ESSAYS ON ENVIRONMENTAL REGULATION: EMISSIONS PERMIT MARKETS AND FIRM STRATEGY

BY

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This dissertation examines the susceptibility of emissions permit systems to strategic behavior among firms. The first chapter models strategic behavior among regulated firms in the market for sulfur dioxide emissions allowances. The strategic incentive of utilities with market power to manipulate the permit price depends on whether they are net sellers or net buyers of permits. In addition, firms subject to rate-of-return regulation have an incentive to raise the price strategically if permits enter the rate base as assets. The interaction of these incentives may prevent emissions reduction at least cost and in equilibrium may lead to a lower volume of permit trading among firms.

The second chapter provides one possible explanation for the stylized fact that polluting utilities are significantly over-controlling their emissions and banking unused permits. A two-stage game is used to analyze permit banking by an incumbent monopolist in order to deter the entry of an independent power producer in a future period. If the potential entrant enters in the second period, the firms compete in a quantity-setting game. If the potential entrant does not enter, the incumbent remains a monopolist in the second period. In the first period, the incumbent chooses its first period output and the quantity of permits to bank for use in the second period. This choice of permits affects its second period cost and therefore, the equilibrium outcome.

The third chapter analyzes a regulator's use of a permit system to achieve economic efficiency in the presence of production externalities when decentralized bargaining is possible. In a conventional permit system, polluting firms purchase permits in individual units, but this system alone cannot sustain the social optimum because it is vulnerable to bargaining. Instead, a block permit system sustains the socially efficient allocation. Polluting firms purchase permits in blocks, and a firm must purchase a minimum of one block in order to enter the industry. A block contains exactly enough permits to enable the holder to emit the socially optimal level of pollution per firm. Block permit sales prevent the polluting industry from bargaining to avoid franchise taxes on entry.

CHAPTER 1
INTRODUCTION

The use of an emissions permit system to achieve environmental quality objectives represents a growing trend in regulatory policy. The purpose of the permit system is the attainment of a specific level of emissions at minimum cost. This approach utilizes economic incentives to promote cost-minimizing emissions reduction, technological innovation, and conservation initiatives. Firms with relatively expensive emissions control technologies will have the incentive to buy allowances, and firms with relatively inexpensive technologies will have the incentive to sell allowances.[1] An important feature of this mechanism is the flexibility that it gives polluting firms in their choice of compliance options.

In general, a regulator determines an aggregate quantity of pollution emissions that is allowable in a given year. It then allocates or sells through an auction a quantity of permits such that the total quantity of emissions equals this cap.[2] An allowance is a certificate that authorizes the owner to emit a unit of pollutant in the current year or any subsequent year.[3] In this system, environmental compliance requires that firms releasing pollution into the atmosphere possess an emission allowance or permit for each unit of emitted pollutant.[4] At the end of each year, a polluting firm must possess a quantity of allowances equal to or greater than its annual emissions. Failure to satisfy the compliance requirement incurs a major penalty for noncompliance.

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[1] See Montgomery (1972). Throughout the chapters, the terms "permit" and "allowance" are used interchangeably.

[2] In an emissions permit system (EPS), the regulator denominates permits in units of pollutant emitted; that is, one permit gives the owner the right to emit one ton of pollutant into the atmosphere. The EPS implies that trades between firms are at a one-to-one rate. For example, if firm A sells one permit to firm B, then firm A must reduce its emissions by one unit. As a result, total emissions remain the same.

One of the first and most significant applications of this performance-based regulation is the 1990 Clean Air Act Amendments (CAAA) Title IV implementation of a market in sulfur dioxide emissions rights. Congress passed this legislation in response to growing concerns about acid rain, a result of coal-fired electric utilities emitting sulfur dioxide into the atmosphere. The purpose of Title IV is to decrease annual sulfur dioxide emissions from nineteen million tons in 1980 to approximately nine million tons by the year 2000.

Compliance is scheduled to occur over two phases. Phase I began in 1995 and affected one hundred ten utilities (over two hundred fifty generating units) with an emissions rate of 2.5 pounds of sulfur dioxide per million British thermal units (SO_2

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[3] Some emissions permit systems allow firms to bank allowances and use them in future years.

[4] Tietenberg (1985) makes the distinction between an emissions permit system (EPS) and an ambient permit system (APS). For non-uniformly mixed pollutants, trades under an EPS could potentially violate ambient quality standards. The APS attempts to resolve this problem because permits in this system are denominated in units of damage at receptors. Generally, a separate permit market exists for each receptor, and firms must trade in the markets for the receptors which their emissions affect.

lbs./mmBtu) and with a capacity greater than one hundred megawatts[5]. Phase II begins in the year 2000 and affects additional units with smaller capacities and imposes a more stringent emissions reduction target.

Firms typically acquire permits either through an endowment from the regulator, from periodic auctions, or from the permit market.[6] The Environmental Protection Agency (EPA) endows allowances annually at zero cost to affected units and allocated the first endowments for Phase I in 1995.[7] For Phase II, which begins in 2000, the EPA will reduce the annual limit on emissions and therefore the number of permits for these allocations. The EPA holds an annual auction for fifty thousand spot allowances and one hundred thousand seven year advance allowances. A single bidder, Allowance Holdings Corporation (AHC), represents several utilities and has dominated the advance auctions to date. Allowances are fully tradeable commodities - they may be purchased, sold, or banked by any corporation, government entity, environmental group, other interested party, or private citizen. Permits obtained from any of these sources may be used or sold in the current year or banked for use or sale in any future year.[8]

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[5] The generating units that equal or exceed these criteria are designated as "affected" units.

[6] CAAA provisions make additional (reserve) allowances available for the installation of qualifying Phase I technology, implementation of customer-oriented conservation measures or renewable energy generation, and for EPA auctions.

[7] The EPA allocates Phase I allowances to each generating unit at an emissions rate of 2.5 SO_2 lbs. /mm Btu of heat input, multiplied by the unit's baseline mmBtu (average fossil fuel consumption from 1985 to 1987).

[8] In contrast, firms may not borrow against future allowance endowments.

Prior to the passage of the CAAA, regulation was essentially technology-forcing with little, if any, choice among compliance options for electric utilities. Unlike this command-and-control approach, an emissions permit system provides compliance flexibility. Electric utilities may use a combination of fuel switching and/or blending, emissions scrubbing (flue gas desulfurization), facility substitution, plant retirement/repowering, energy conservation, and demand side management to reduce their emissions. The only requirement for polluting units is that each affected generating unit must possess a permit for each ton of sulfur dioxide emitted in that year.[9]

Measures of the success of the permit market's operation generally focus on the volume of trading activity. From the initiation of the program, trading activity has been significantly lower than originally expected. The largest share (nearly forty-eight percent) of allowance trades involving utilities has occurred between brokers and utilities. Intra-utility trades comprise twenty-five percent of trades, and the volume of inter-utility trades constitutes twenty percent.[10]

Although the illiquidity of the allowance market has prevented the full realization of the originally projected cost savings, it is not necessarily the best measure of the program's effectiveness. A more appropriate economic criterion is productive efficiency or the program's attainment of emissions reduction targets at minimum abatement cost.[11] Burtraw (1996) argues that despite this illiquidity, the program has been largely successful because its performance-based structure has enabled utilities to benefit from exogenous changes in input markets and from competition among these markets.[12]

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[9] January 1 to January 30 is the "true-up" period following a compliance year during which utilities may acquire the necessary allowances to equate the number in their possession with total tons of sulfur dioxide emitted during the compliance year. Bailey (1996) gives a complete description of the compliance protocol.

[10] A generating unit that is an affected unit must satisfy compliance. Obviously, some utilities have multiple affected units. An intra-utility trade implies that a utility reallocates allowances among its units for compliance purposes.

The most significant development in these related markets has been the decline in the price of low sulfur coal. The delivered price of low sulfur coal has remained unexpectedly low and is expected to remain low as the result of higher mining productivity and greater competition in the rail sector.[13] It is no surprise that fuel switching to and blending with low sulfur coal have been the most popular compliance options among utilities especially given that this strategy involves little risk relative to other options, such as investment in abatement technologies. This low marginal cost compliance option has made Phase I emissions reductions targets attainable at relatively low cost.

Trading activity likely will contribute significantly to the economic success of the program in the near future. Greater divergences in the marginal abatement costs of utilities are likely to emerge as the price of low sulfur coal eventually increases, and they gradually adopt other compliance strategies. In addition, many utilities have achieved Phase I compliance by shifting their production to generating units that are unaffected until Phase II. With the beginning of Phase II of the program, these units must satisfy compliance standards as well. Other factors, such as uncertainty about the future restructuring of the electricity industry, imply that permits may be more highly valued by utilities as a form of insurance.[14] These possibilities indicate that the efficient operation of the allowance market will be essential for continued cost savings.

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[11] Allocative efficiency is a second criterion.

[12] Burtraw (1996), pp. 79-80.

[13] Burtraw (1996), p. 85.

At the same time, the market is not without potential problems. Like any other market, it is susceptible to strategic behavior that inhibits its efficient operation. Essentially, strategic incentives make firms' profit-maximizing objectives incongruent with emissions reduction at minimum cost. Strategic incentives may originate from the design of the market or from the opportunities it provides to participants.

This dissertation analyzes strategic behavior by firms that interferes with the cost-minimizing objectives of an emissions permit system. This behavior in the specific context of the market for sulfur dioxide emissions rights is examined in the first two chapters. This setting is useful because it is one of the first and most comprehensive attempts to control pollution through the creation of a "missing market." The third chapter also addresses strategic incentives that upset the function of an emissions permit system but uses a more general setting.

The first chapter of the dissertation considers market power in the market for sulfur dioxide emissions rights and analyzes its effect on firm decision-making. One potential source of market power in such a system is the initial distribution of permits to firms. In Phase I, initial endowments are distributed at zero cost to the one hundred ten of the "dirtiest" coal-fired electricity generating units. Major polluting firms that acquire a significant share of permits may be able to affect the permit price strategically to their benefit under certain conditions.

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[14] In both 1995 and 1996, utilities banked for future use and/or sale over thirty-three percent of the annual allowances issued.

This strategic issue is complicated by the fact that participating utilities are subject to significant regulatory constraint by state public utility commissions (PUCs). The PUCs determine an allowed return on a utility's investment, and in this rate making procedure, they evaluate a utility's fuel and capital costs. This process also requires the regulatory treatment of a utility's environmental compliance choices, including permit purchases and sales as well as investments in abatement technology. The outcome of this rate making process affects utilities' compliance decisions because any disparities in the treatment of compliance options alter firm incentives.[15]

The second chapter addresses the use of emissions allowances for anticompetitive purposes. It provides one possible explanation for the stylized fact that large polluting utilities are over-controlling their emissions and banking their unused permits. The analysis focuses on an incumbent utility's incentive to bank permits in order to deter the entry of a potential competitor into a regional market for electricity generation.

This strategic possibility is especially relevant as the U.S. electricity industry moves toward a more competitive market structure. Competition at the wholesale level has begun, and restructuring will facilitate additional competitive opportunities. Incumbent monopoly utilities are generally larger and dirtier coal-fired generators while potential entrants are smaller and cleaner independent power producers. Although banking permits yields no benefits in the current period, it reduces a firm's future costs. Therefore, allowance banking in the current period represents a commitment to produce more output in the future.

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[15] Another complicating factor is that these PUC regulations differ across states. This variance potentially affects industry-wide compliance costs as well. Finally, utilities' uncertainty about the rate making treatment of allowances has implications for the operation of the permit market. See Bailey (1996) and Sotkiewicz (1997).

The third chapter demonstrates that conventional emissions permit markets, in which permits are purchased in individual units, are susceptible to strategic behavior by firms. Coasian bargaining between polluting and damaged industries leads to inefficiencies in the operation of a conventional permit system if free entry of firms into either industry is possible. Firms bargain to maximize the joint profits of the industries and in this process, they account for the social costs of pollution. Firms economize on permit use and drive the market price to zero, inducing additional firms to enter the polluting industry. In order to sustain the socially optimal level of pollution with a permit system, the government must make permits available only in blocks, not in individual units. A block permit system is impervious to strategic bargaining among firms.

The common theme of these chapters is that the ability of an incentive-based emissions permit system to achieve a specific emissions target at minimum cost may be compromised by strategic behavior among firms. This behavior may involve the strategic purchase or sale of permits to affect their market price. In this case, the presence of an additional regulatory constraint creates further distortions in firms' incentives. A second possibility is the use of permits as instruments for strategic entry deterrence. The flexibility given by allowance banking enables the acquisition of permits for anticompetitive purposes. Finally, the ability of firms to bargain strategically with each other prevents the attainment of a socially efficient outcome if free entry is possible. This strategic negotiation also undermines the cost-minimizing function of a conventional permit system.

CHAPTER 2
STRATEGIC INTERACTION IN THE MARKET FOR EMISSIONS PERMITS

2.1 Introduction

The purpose of Title IV of the Clean Air Act Amendments (CAAA) of 1990 is to reduce significantly national annual sulfur dioxide (SO_2) and nitrogen oxide emissions. Specifically, this legislation requires more than a fifty percent reduction of sulfur dioxide emissions relative to 1980 benchmark levels. Such a reduction implies that sulfur dioxide emissions will decrease to 8.95 million tons by the year 2000. Regulated investor-owned utilities (IOUs) generate the majority of sulfur dioxide emissions; therefore, Title IV establishes a separate and distinct regulatory system for electricity generation sources.

Compliance with the CAAA is a gradual process and is scheduled to occur over two phases. The legislation targets units for compliance based on their quantity of sulfur dioxide emissions and their generating capacity. Phase I began in 1995 and affects one hundred ten plants that individually have an emissions rate of 2.5 pounds of sulfur dioxide per million British thermal units (SO_2 lbs./mmBtu) and have a capacity exceeding one hundred megawatts. This phase is scheduled to reduce sulfur dioxide emissions to a level equal to an emissions rate of 2.5 SO_2 lbs./mmBtu times an average of the firm's 1985-1987 fuel use. Phase II objectives include reducing the emissions limit to 1.2 SO_2

lbs./mmBtu, and Phase II units include all fossil-fueled boilers with a capacity exceeding twenty-five megawatts and any additional units.

The CAAA provide for the creation of a market in transferable emissions permits to increase utilities' compliance options and to reduce their compliance costs.[1] Although the implementation of an emissions permit system (EPS) represents a recent development in public policy, the original idea for this mechanism is not new.[2] In the context of the CAAA, an emission allowance or permit is a property right to emit one ton of sulfur dioxide in the year issued or in any subsequent year.[3] Units designated as Phase I or Phase II affected units must comply with the relevant provisions for sulfur dioxide emissions reduction.[4] Compliance means that all affected units must obtain the necessary allowances to cover their emissions. A polluting firm must possess a number of allowances equivalent to tons of sulfur dioxide emitted in the present year.[5] Firms may receive permits from the regulator (as cost-free endowments), the permit market, and from periodic auctions.[6]

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[1] The basis for the effective operation of such a market is the legal status of these allowances as transferable property rights. In §403(f) of the CAAA, however, Congress specifies that "allowances do not constitute a property right." The legal motive behind this ruling is the preclusion of allowances as compensable property rights under the Fifth Amendment. At the same time, Congress has determined that allowances are assets.

[2] Research by Dales (1968) first developed the idea of a market in pollution rights. His proposition that property rights should be defined for environmental resources and then distributed through an auction provides an alternative remedy to effluent fees.

[3] Firms have the option to bank allowances for later use and/or sale. Throughout the chapter, the terms "allowance" and "permit" are used interchangeably.

[4] The CAAA provide for the EPA's allocation of allowances to existing "affected units." An affected unit is a generating unit in operation prior to the passage of the CAAA that emits more than the legal limit.

The use of a system of tradeable pollution permits as a mechanism to correct negative externalities is popular among environmental economists. Unlike traditional command-and-control regulation, this system recognizes that the cost of pollution abatement varies across generating units. Proponents of a market in emissions rights emphasize that the primary benefit is the attainment of a specific level of emissions reduction at minimum cost. Firms with relatively inexpensive emissions control methods will not use the allowances. Firms with relatively expensive emissions control methods will purchase additional allowances because their control costs exceed the expected allowance price. The driving force behind the trade of allowances is the utilities' search for a cost-minimizing solution. The expected result is that the marginal cost of physical abatement equals the allowance price.

This reduction of emissions at minimum cost relies on the absence of market imperfections and prohibitive transactions costs. A limited number of polluters accounting for a significant proportion of emissions is one potential market imperfection. The Phase I allocations are distributed among one hundred ten plants (more than two hundred sixty units) on the basis of baseline emissions. The EPA allocates initial allowances to existing utilities on an annual basis using a baseline emissions formula that multiplies the affected unit's emission rate by its average fuel consumption. This formulation implies that the larger and dirtier utilities receive larger shares of the total number of allowances *ex ante* while smaller and cleaner utilities receive smaller shares. For Phase I, the top five utilities receive allowances that account for forty-six percent of total allowances, and the top twenty utilities receive allowances that account for eighty percent of the total allowances.

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[5] In an emissions permit system (EPS), the regulator denominates permits in units of pollutant emitted; *i.e.*, one permit gives the owner the right to emit one ton of pollutant into the atmosphere. The EPS implies that trades between firms are at a one-to-one rate. For example, if firm A sells one permit to firm B, then firm A must reduce its emissions by one unit. Firm B now may augment its emissions by one unit; as a result, total emissions remain the same.

[6] For analytical tractability, the model in this chapter limits sources of permits to endowments and the market.

The possibility of market power in markets for emissions rights is an imperfection that has received attention in the economics literature. Hahn and Noll (1982) discussed the possibility that strategic behavior by the major polluters prevents the permit market mechanism from allocating permits to minimize total abatement costs. Hahn (1984) examined the way in which a firm with market power exerts its influence. He showed that strategic behavior prevents least cost emissions reduction because it induces firms to deviate from the competitive price-quantity equilibrium. Specifically, if a firm with market power chooses to sell allowances in a competitive market, then that firm strategically behaves like a monopolist. Similarly, if a firm with market power elects to buy allowances in a competitive market, then that firm strategically behaves like a monopsonist.

This strand of research is incomplete in the context of tradeable pollution permits for sulfur dioxide emissions. The primary players in the emissions permit market are IOUs that are also subject to rate-of-return regulation. Tschirhart (1984) analyzed the effect of a rate-of-return constraint on the behavior of an individual profit-maximizing utility that participates in an allowance market. Following Tschirhart, Hahn (1991), Patrick (1992), Coggins and Smith (1993), and Cronshaw and Kruse (1996) also examined the behavior of firms subject to both environmental and rate-of-return regulation. Although these authors analyzed firm behavior under both constraints in different settings, they did not consider the partial or full inclusion of permits in a regulated firm's rate base.

State public utility commissions' (PUCs) rate making treatment of allowances is an important issue because it potentially affects firms' behavior in reducing emissions at minimum cost - the primary objective of the emissions market. Current PUC rate making practices with respect to emission allowances are varied, and rate making treatment is an unresolved issue in many states. Only fifteen state PUCs have formalized their position on allowance trading and regulation.[7] These states are mostly ones with Phase I affected units. Phase II's more inclusive definition of affected unit will subject currently unregulated units in other states to compliance requirements. As a result, the PUCs' regulatory treatment of allowances is likely to grow in importance.

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[7] State PUCs issue either a formal generic order or an informal guideline.

Rose *et al.* (1992) developed a model that accounts for a full range of rate making rules, from full expensing of permits to their full inclusion in the rate base. They found that a regulator's differential treatment of abatement capital and permits induces firms to choose an input combination for emissions reduction that is not cost-minimizing.

In a general analysis of strategic behavior in a market by dominant firms, one conclusion is that sellers of the good want to increase the price of the good strategically, and buyers want to decrease the price strategically. This conclusion also applies to a permit market with dominant firms: net sellers of permits want a higher price, and net buyers of permits want a lower price. This incentive affects a utility's cost-minimization incentives for emissions reduction because it causes the firm to either overutilize or underutilize (respectively) permits relative to abatement capital.

The added dimension of strategic behavior in the permit market introduces a second distortion in firm behavior if the regulator allows partial or full inclusion of permits in the rate base. Any inclusion provides firms with market power an additional incentive to manipulate the permit price strategically because the asset value of permits enters the rate base. As a result, net sellers of permits with strategic power want a higher permit price because they benefit from higher revenues on sales and from a higher capitalized value in their rate base. For net buyers of permits, their incentives conflict. They want a higher price because the asset value enters the rate base, but at the same time, they want a lower price because they benefit from lower costs on purchases of permits.

Although the move toward competition is underway in the electricity industry, the complexity of issues and the number of involved parties make the ultimate outcome of restructuring uncertain. The evolution of current market structures toward more competitive ones will take time. Federal and state regulatory oversight of utility practices is likely to retain a significant function. At the same time, the contribution of coal-fired generation to electricity production will continue to justify the need for environmental regulation. As a result, the interaction of rate-of-return and environmental constraints may have a significant impact on the ability of the permit market to achieve emissions reduction at minimum cost. The potential for strategic behavior, which is more likely as environmental constraints become more binding, is an additional complexity that affects the efficiency properties of the emissions system as well.

2.2 Firm Optimization

2.2.1 Nonstrategic Behavior

In this section, firm incentives for reducing emissions in the presence of rate-of-return regulation are examined. The market for emissions allowances is assumed to be competitive. Firms do not possess market power and cannot affect the allowance price strategically. In this context, firms take the allowance price as given. This analysis provides a cost-minimizing benchmark for a firm's choice of abatement and permits to attain environmental compliance.

2.2.1.1 No Rate-of-Return Regulation

All n firms that participate in the allowance market have some degree of monopoly power in their respective output markets for electricity. Let q be the output of generated electricity. Each firm faces an inverse demand $p(q)$ with $p'(q) < 0$. Each firm's inverse demand may be different.[8] A firm's revenue function is $R(q) \equiv p(q)q$. It uses fuel (x) and capital (k) to produce this output and purchases these inputs at competitive prices, $w > 0$ and $r > 0$ respectively. The production function $f(x,k)$ relates the output and the two inputs such that $q \leq f(x,k)$. A firm's profit function is

(*1*) $\pi \equiv R(q) - wx - rk$.

If a firm is unregulated then it chooses q, x, and k to maximize its profit (π) subject to

(*2*) $q \leq f(x,k)$ with $q \geq 0$, $x \geq 0$, and $k \geq 0$.

The standard assumptions underlying the production function are $f(0,0) = 0$, $f_x \equiv \partial f/\partial x >$ 0, and $f_k \equiv \partial f/\partial k > 0$, where f_x and f_k are the marginal products of fuel and capital respectively.

This production process involves the generation of sulfur dioxide emissions. In complying with the legal requirements of the CAAA, a firm may emit as many tons of sulfur dioxide as it desires, provided it possesses *at least* as many allowances; that is, a firm with positive emissions must use the requisite allowances or pay a noncompliance penalty.[9] In this model, a firm may relax this constraint by altering its level of output, purchasing abatement capital (a), or acquiring additional permits.[10]

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[8] Asymmetric output markets do not affect the results qualitatively.

[9] This model is not a dynamic one; therefore, firms cannot bank allowances for future use or sale. Cronshaw and Kruse (1996) developed a dynamic model to examine firm incentives in emissions markets.

[10] Although fuel switching is another possibility, allowing for this option complicates the model and is not directly relevant to the analysis.

A firm's emissions are related to the output level and the quantity of abatement capital by the function, $e = h(q, a)$. For a fixed level of abatement, emissions increase with an increase in output ($h_q > 0$). Emissions decrease with an increase in abatement capital ($h_a < 0$) given output remains constant. The firm may obtain any quantity of abatement capital at the competitive price, $r > 0$.

The government regulator determines the fixed supply of allowances ($\bar{L}$) to distribute among the firms. Each of the n firms receives an initial endowment, L_i, of allowances such that $\sum^{n}_{i=1} L_i = \bar{L}$. Let l represent the number of licenses or allowances the firm *uses* for compliance in a given year. One pollution allowance permits the emission of one ton of sulfur dioxide. Allowances may be bought and sold freely by the firms at the market-clearing price (p_l) since none of them possesses market power. The firm is subject to the additional constraint on emissions:

(3) $h(f(x,k),a) \leq l.$

In summary, a utility earns revenue from the sale of electricity and from any allowances sold; that is, a net supply of permits ($L_i - l_i > 0$) is an addition to revenue, and a net demand for permits ($L_i - l_i < 0$) is an addition to costs. A utility's costs (net of permits) include expenditures on fuel, capital, and abatement capital. These additional components allow the reformulation of the firm's profit function:

(4) $\pi \equiv R(q) - wx - r(k + a) + p_l(L_i - l_i).$

The implicit assumption that the cost and emissions functions are separable is reasonable because in general, utilities equipped with coal-fired generating units were retrofitted with scrubber technology at a later date.

2.2.1.2 Rate-of-Return Regulation

Rate-of-return regulation is one of the most researched topics in the field of regulatory economics. This approach remains a popular regulatory instrument with state and federal commissions for the regulation of IOUs. The actual process involves several steps, including a commission's review of costs and subsequent determination of a fair rate-of-return to productive capital.

This method of regulation compels the regulator to confront significant informational requirements. The rate level problem requires the regulator to determine an appropriate level of earnings for the firm's investment. The regulator must then set an allowed rate-of-return (s) without precise knowledge of the firm's true cost of capital (r). The regulator ideally prefers that the allowed rate is set as closely as possible to the true cost of capital.

Although rate-of-return regulation produces some desirable benefits for consumers, it may adversely affect the behavior of utilities. First, a utility may pass on specific costs to its customers and as a result, not minimize its costs. A second and more researched effect relates to a firm's choice of inputs. Averch and Johnson (1962) first addressed the effect of rate making biases, specifically the asymmetric rate making treatment of capital assets relative to non-capital assets. They showed that the asymmetry of the profit constraint induces a firm to operate with an inefficiently high capital/labor ratio for a given level of output.[11]

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[11] See Berg and Tschirhart (1988) for a more detailed description.

The addition of a rate-of-return constraint to this model first requires consideration of the rate base treatment of assets.[12] The rate base fully includes both capital and abatement capital. The placement of abatement capital in the rate base is consistent with standard commission practices in forty-nine states.[13] The current rate making treatment of emission allowances varies from state to state, and some states have not made rulings.[14] Let θ represent the proportion of allowances included in a firm's rate base. The full inclusion of allowances in the rate base ($\theta = 1$) is the cost-minimizing rule with respect to emissions reduction because almost all states allow full inclusion of abatement capital. Some PUCs have elected either full or partial exclusion of allowances from the rate base ($0 \leq \theta < 1$) in order that consumers do not bear significant compliance costs. In this model, it is assumed that $0 \leq \theta \leq 1$ to consider all possibilities.

An emission allowance is a certificate to emit one ton of sulfur dioxide, and by assumption, it has an infinite life. Assume that it generates a coupon in each period and that this coupon is redeemable. The one period coupon price is p_l, and the asset price or capitalized value of the allowance is p_l / r. The price of an allowance, p_l, enters the firm's profit function directly.[15]

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[12] The rate base treatment of assets is a complex issue. This model simplifies rate making issues considerably to make the analysis more tractable but attempts to retain the essential features. Alternative rate base assumptions are relegated to a later section.

[13] See the discussion in Rose *et al.* (1992).

[14] See Bailey (1996) for a comprehensive discussion.

[15] Rose *et al.* (1992) allow for this possibility.

The problem of a representative firm (designated firm 1) which is a participant in the market for emissions permits is analyzed. Firm 1 maximizes its profit (*4*) subject to the production constraint (*2*) and the government-imposed constraint on emissions (*3*) by choosing x, k, a, and l_1. The firm also faces the rate-of-return constraint. The firm's rate base is

(*5*) $k + a + \theta l_1 (p_l / r)$

where the fraction of used allowances earning a return is θ. The firm's net operating income is

(*6*) $R(q) - wx + p_l[L_1 - l_1(1-\theta)]$

where the value of the fraction of used allowances not included in the rate base is a deduction. From (*5*) and (*6*), the regulatory constraint is

$$(7)\quad R(q) - wx + p_l[L_1 - l_1(1-\theta)] \le s\left(k + a + \frac{\theta p_l l_1}{r}\right)$$

where s is the allowed rate-of-return, and r is the firm's cost of capital. The assumptions of an interior solution and positive profit ($\pi > 0$) imply that $s > r$. The firm then maximizes economic profit (*4*) subject to (*2*), (*3*), and (*7*), choosing x, k, a, and l_1. This constrained optimization problem is the program for the *nonstrategic regulated* case [N-R] (see Section *2.6*).

Lemma 1: *If the firm maximizes economic profit* (*4*) *subject to* (*2*), (*3*), *and* (*7*), *and an interior solution exists; i.e.,* $x > 0$, $k > 0$, $a > 0$, *and* $l_1 > 0$, *then* $\mu > 0$ *and* $0 < \lambda < 1$ (*where* μ *is the emissions constraint Lagrange multiplier, and* λ *is the rate-of-return constraint Lagrange multiplier*).

Proof: See 2.6. For all other proofs, see 2.9.

The first order conditions (*A1.1-A1.7*) imply that a firm not subject to rate-of-return regulation ($\lambda = 0$) minimizes cost in its choice of all inputs. The firm makes a cost-minimizing decision in its choices of fuel and capital because of the absence of the rate-of-return constraint. Also, the firm makes a cost-minimizing decision in its choices of abatement capital and allowances because of the absence of both the rate-of-return constraint and any strategic incentives.

With rate-of-return regulation, the inclusion of capital in the rate base creates a bias in favor of its use relative to fuel. The inclusion in the rate base of any proportion of allowances less than one ($0 \leq \theta < 1$) causes a bias in favor of abatement capital use relative to permit use. The following theorem restates the Averch-Johnson result in (*i*) and presents the analogous result for the input choice between abatement capital and permits in (*ii*).

Theorem 1: *With nonstrategic behavior in the allowance market and with rate-of-return regulation, if* $0 \leq \theta < 1$,

(*i*) *the marginal rate of technical substitution between capital and fuel is less than the input price ratio*

$$(8a)\quad \frac{f_k}{f_x} = \frac{r - \lambda s}{w(1-\lambda)} < \frac{r}{w} \;;$$

(*ii*) *the marginal product of capital in reducing emissions is less than the marginal cost*

$$(8b)\quad \left(\frac{-\partial h}{\partial a}\right)^{NR} = \frac{r}{p_l}\left[\frac{r - \lambda s}{r(1-\lambda) - \lambda(s-r)\theta}\right] < \frac{r}{p_l} \;.$$

Theorem 1 provides the nonstrategic benchmark for future comparison. Property (*i*) is the Averch-Johnson overcapitalization effect.[16] The rate base treatment of capital induces use of more capital relative to the cost-minimizing choice for a given level of output. Property (*ii*) depends on the value of the parameter, θ. For $0 \leq \theta < 1$, the firm uses more than the cost-minimizing quantity of abatement capital relative to permits in reducing emissions.

For a given level of allowances, the regulated firm faces a relatively lower marginal cost of abatement than the unregulated firm. As a result, in equilibrium, the regulated firm uses less allowances than the unregulated firm. This effect is the *nonstrategic rate base effect.* For $\theta = 1$, the firm makes the cost-minimizing choices because the symmetric rate base treatment of the two inputs does not create a distortion.

2.2.2 Strategic Behavior

This section captures the possibility of strategic interaction among firms in the market for emissions permits. The structure of the allowance market plays a crucial role in the analysis (see Figure *2-1* for a graphical depiction of the following framework). By assumption, the market is no longer competitive, and there are two dominant firms (designated firms 1 and 2). These firms are dominant in the sense that they are Cournot quantity-setters in the permit market.[17] Each dominant firm's choice of allowances affects the other firm's choice of allowances, and this competition affects the equilibrium price of allowances. The remaining *n*-2 firms have no market power and behave as price takers. In effect, these *n*-2 firms form a competitive fringe.

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[16] The cost-minimizing input ratios (*i*) for capital and fuel (r/w) and (*ii*) for capital and allowances $(-\partial h/\partial a)^E = (r/p_l)$ prevail in the absence of rate-of-return regulation where $(-\partial h/\partial a)^E$ is the notation for the cost-minimizing input price ratio for emissions permits and abatement.

Lemma 2: *If* (*i*) *the competitive fringe has the inverse demand for allowances,* $p^f_l(l_f) = \alpha - \beta l_f$, *where* α *and* β *are positive constants and* l_f *is the quantity of allowances demanded, and* (*ii*) *the competitive fringe and the dominant firms face the perfectly inelastic supply of allowances,* $\bar{L}$, *then market-clearing implies that the dominant firms face the inverse supply,* $p^f_l(l_f)$, *and the equilibrium strategic price is* $p^{sr}_l = p_l[(l_1, l_2)]$.

The dominant firms compete for allowances taking the fringe demand as given, while the price-taking competitive fringe remains idle. Cournot competition determines the equilibrium choices of l_1 and l_2, and their sum gives the equilibrium strategic price, $p^{sr}_l = p_l[(l_1, l_2)]$, to both the dominant firms and the fringe.

Consider a representative strategic player (firm 1) that maximizes its profit by choosing x, k, a, and l_1 subject to constraints on production, emissions, and profit. This firm is a Cournot quantity-setter in the allowance market and faces the inverse supply of allowances given by $p^{sr}_l = p_l[(l_1, l_2)]$. By assumption, an interior solution exists in this problem; that is, $x > 0$, $k > 0$, $a > 0$, and $l_1 > 0$. The program for the *strategic regulated* case [S-R] is in Section *2.7*.

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[17] More than two dominant firms could exist in the market; however, this possibility does not affect the qualitative results.

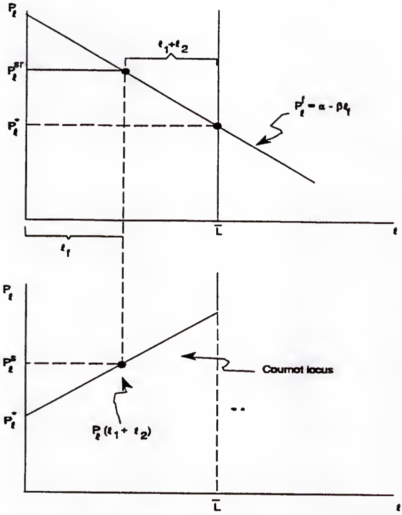

Figure *2-1*: Strategic Equilibrium

The first order conditions for an interior solution (*A2.1-A2.7*) imply that a firm not subject to rate-of-return regulation does not make the cost-minimizing input choices due to its strategic incentives. If an individual firm can affect the allowance price strategically, then a net seller of allowances utilizes relatively more than the cost-minimizing level to reduce the quantity available on the market. This action raises the allowance price because the price depends on the aggregate quantity of allowances. Similarly, a net buyer of allowances utilizes relatively less than the cost-minimizing level to augment the quantity available which lowers the allowance price.

A dominant firm in the allowance market uses allowances in a strategic fashion to affect the market price to its benefit. Specifically, a net seller acts like a monopolist in order to raise the price over the units it sells, and a net buyer acts like a monopsonist in order to lower the price over the units it buys.

Theorem 2: *With strategic behavior in the allowance market and with rate-of-return regulation, a dominant firm's abatement/allowance input decision is characterized by*

$$(9)\quad \left(\frac{-\partial h}{\partial a}\right)^{SR} = \frac{r-\lambda s}{\mu} = \left[\frac{r(r-\lambda s)}{p_l[r(1-\lambda)-\lambda(s-r)\theta]-p'_l[r(1-\lambda)(L_1-l_1)+\lambda(s-r)\theta l_1]}\right].$$

An examination of μ, the shadow price of emissions, provides further insight. The shadow price is

$$(10)\quad \mu = p_l\left[(1-\lambda) - \frac{\lambda(s-r)\theta}{r}\right] - p_l'\left[(1-\lambda)(L_1-l_1)+\frac{\lambda(s-r)\theta l_1}{r}\right].$$

The question of interest in this chapter is how strategic behavior in the allowance market affects a dominant firm's decisions. In this context, the remainder of this section compares a firm's emissions decision in the nonstrategic regulated regime [N-R] to its decision in the strategic regulated regime [S-R].[18] This comparison depends on whether the firm is a net seller or a net buyer of allowances.

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[18] This approach involves comparing nonstrategic to strategic input ratios, each ratio containing an allowance price determined within its respective regime. Section *2.3* demonstrates the comparability of prices from two different regimes.

The status of a firm as a net seller or net buyer determines the sign of the second term in (*10*). This term reflects the strategic aspect of the problem and serves as the source of any distortion from the [N-R] abatement/allowance input ratio. The first component within the brackets (multiplying p_l') of the second term is the *strategic* (*net*) *wealth effect*. A firm's allowance endowment is a source of wealth, and a change in the allowance price affects the value of the endowment. The second component within the brackets is the *strategic rate base effect*. This effect implies that a firm, regardless of its status as a seller or buyer, wants a higher allowance price because a higher asset value enters directly into the firm's rate base.

For a net seller of allowances ($L_1 - l_1 > 0$), the entire bracketed term is unambiguously positive for all values of θ. The firm wants to use its market power to raise the allowance price for two reasons: *i*) as a net seller, a higher price increases the value of its net sales, that is, increases its wealth; and *ii*) a higher price increases the asset value in its rate base. These two strategic incentives induce the seller to overutilize allowances to raise their market price. As a result, the seller's *net* strategic effect ameliorates the nonstrategic rate base effect, and the seller's [S-R] input ratio, in general, is more cost-minimizing relative to the [N-R] case.

Theorem 3a: *With strategic behavior in the allowance market and with rate-of-return regulation,*

(*i*) *if* $(p_l)[\lambda(s-r)(1-\theta)] > p_l'[r(1-\lambda)(L_1-l_1)+\lambda(s-r)\theta l_1]$, *then a net seller's abatement/allowance input decision is closer to the cost-minimizing ratio than the nonstrategic regulated case*; *i.e.*,

$$\left(-\frac{\partial h}{\partial a}\right)^{E} > \left(-\frac{\partial h}{\partial a}\right)^{SR} > \left(-\frac{\partial h}{\partial a}\right)^{NR} \quad ;$$

(*ii*) *if* $(p_l)[\lambda(s\text{-}r)(1\text{-}\theta)] < p_l'[r(1\text{-}\lambda)(L_1\text{-}l_1)+\lambda(s\text{-}r)\theta l_1]$, *then a net seller's abatement/allowance input decision may or may not be closer to the nonstrategic regulated case; i.e.,*

$$\left(-\frac{\partial h}{\partial a}\right)^{SR} > \left(-\frac{\partial h}{\partial a}\right)^{E} > \left(-\frac{\partial h}{\partial a}\right)^{NR} \quad .$$

The marginal productivity of abatement capital in reducing emissions ($-\partial h/\partial a$) is the slope of a given emissions isoquant. A firm employs the cost-minimizing quantities of abatement capital and allowances when this marginal productivity is equal to the ratio of the marginal costs of the respective inputs, that is $(-\partial h/\partial a)^{E} = r/p_l$.

Theorem 1 establishes that the [N-R] case yields an input ratio that is less than the cost-minimizing one. The [S-R] input ratio exceeds the [N-R] input ratio, and the condition in property (*i*) of *Theorem 3a* ensures that the former actually lies between the cost-minimizing input ratio and the [N-R] input ratio. In this case, the [S-R] ratio improves cost minimization of emissions reduction. The condition in property (*i*) also implies $0 \leq \theta < 1$ because $\theta = 1$ does not satisfy it. Property (*i*) implicitly allows for a disparity in the rate base treatment of abatement and allowances.

Property (*ii*) of *Theorem 3a* allows for the possibility that the firm's strategic effect overwhelms the nonstrategic rate base effect. If the condition in property (*ii*) is satisfied, the [S-R] input ratio exceeds the cost-minimizing input ratio. As a result, it is no longer apparent whether the [S-R] ratio actually improves or worsens cost-minimization relative to the [N-R] case.[19] Also, property (*ii*) allows for the symmetric rate base treatment of abatement and permits ($\theta = 1$ satisfies the condition in property (*ii*)).[20] For a net buyer of allowances ($L_1 - l_1 < 0$), the sign of the second term in (*10*) depends on the magnitude of each strategic effect. Like a net seller, the net buyer wants a higher allowance price because this price increases the asset value in the rate base. The strategic rate base effect induces the firm to overutilize allowances in order to raise the market price. In contrast, the strategic wealth effect induces the net buyer to underutilize allowances in order to lower the allowance price, which reduces the cost of its net purchases.

If the strategic wealth effect is larger in absolute value than the strategic rate base effect then the net strategic effect is that the firm underutilizes allowances. This net effect reinforces the nonstrategic rate base effect, and the firm's [S-R] input ratio is *less* cost-minimizing relative to the [N-R] case. A net buyer for which the strategic wealth effect is dominant is a *strong buyer.*

If the strategic wealth effect is smaller in absolute value than the strategic rate base effect, then the net effect is that the firm overutilizes allowances to raise the market price. This net strategic effect ameliorates the nonstrategic rate base effect, and the firm's [S-R] input ratio under certain conditions is *more* cost-minimizing relative to the [N-R] case. A net buyer for which the strategic rate base effect is dominant is a *weak buyer.*

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[19] See the proof of *Theorem 3a*.

[20] In this case, with $\theta = 1$, the [N-R] input ratio is cost-minimizing (equals r/p_l), and the [S-R] input ratio is not cost-minimizing because it exceeds r/p_l.

A brief explanation of the strong buyer - weak buyer nomenclature is in order. A strong buyer is a buyer for which the strategic wealth effect is larger in absolute value than the strategic rate base effect.[21] As a result, the strong buyer actually *underutilizes* allowances even more relative to the [N-R] case. The buyer is designated a strong buyer because the large magnitude of allowance use, given the endowment, induces the firm to lower the permit price strategically even though this action lowers the asset value in the rate base.[22]

The weak buyer *overutilizes* allowances. The buyer is designated a weak buyer because its allowance use is not significantly large enough to cause the strategic wealth effect to outweigh the strategic rate base effect. In other words, the weak buyer receives a greater benefit from a higher asset value in its rate base than from a lower price for its net purchases of permits. As a result, the weak buyer *actually wants a higher allowance price and acts like a seller.* The following theorem summarizes this result.

Theorem 3b: *With strategic behavior in the allowance market and with rate-of-return regulation,*

(*i*) *if* $0 \leq \theta \leq 1$, *then a strong net buyer's abatement/allowance input decision is further from the cost-minimizing ratio than the rate-of-return nonstrategic case*; *i.e.*,

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[21] From equation (*10*), this statement is equivalent to $|r(1-\lambda)(L_1-l_1)| > \lambda(s-r)\theta l_1$.

[22] The two strategic effects exactly offset if there exists an l_1^* such that $|r(1-\lambda)(L_1-l_1^*)| = \lambda(s-r)\theta l_1^*$. Given L_1, the strategic wealth effect is greater if $|r(1-\lambda)(L_1- l_1)| > \lambda(s-r)\theta l_1$, or l_1 is large enough such that $l_1 > l_1^*$; *i.e.*,

$$l_1 > \frac{p_l' r(1-\lambda)}{p_l' r(1-\lambda) - \lambda(s-r)\theta} [L_1] = l_1^* \quad .$$

Section *2.3* gives further clarification.

$$\left(-\frac{\partial h}{\partial a}\right)^{E} > \left(-\frac{\partial h}{\partial a}\right)^{NR} > \left(-\frac{\partial h}{\partial a}\right)^{SR};$$

(iia) if $(p_l)[\lambda(s\text{-}r)(1\text{-}\theta)] > p_l'[r(1\text{-}\lambda)(L_1\text{-}l_1) + \lambda(s\text{-}r)\theta l_1]$, *then a weak net buyer's abatement/allowance input decision is closer to the cost-minimizing ratio than the nonstrategic regulated case; i.e.,*

$$\left(-\frac{\partial h}{\partial a}\right)^{E} > \left(-\frac{\partial h}{\partial a}\right)^{SR} > \left(-\frac{\partial h}{\partial a}\right)^{NR};$$

(iib) if $(p_l)[\lambda(s\text{-}r)(1\text{-}\theta)] < p_l'[r(1\text{-}\lambda)(L_1\text{-}l_1) + \lambda(s\text{-}r)\theta l_1]$, *then a weak net buyer's abatement/allowance input decision may or may not be closer to the cost-minimizing ratio than the nonstrategic regulated case; i.e.,*

$$\left(-\frac{\partial h}{\partial a}\right)^{SR} > \left(-\frac{\partial h}{\partial a}\right)^{E} > \left(-\frac{\partial h}{\partial a}\right)^{NR}.$$

In property (*i*), a strong buyer's net strategic effect induces a choice of inputs that is not cost-minimizing relative to the [N-R] case. This property holds for any θ, $0 \le \theta \le 1$.

Property (*iia*) is analogous to property (*i*) of *Theorem 3a*. The weak buyer strategically behaves like a seller, and as long as the condition in property (*iia*) is satisfied, the [S-R] input ratio for the weak buyer improves cost-minimization relative to the [N-R] input ratio. This condition implies $0 \le \theta < 1$, allowing for the asymmetric treatment of abatement capital and allowances.

Property (*iib*) is analogous to property (*ii*) of *Theorem 3a*. The net strategic effect is too strong in the sense that the [S-R] input ratio exceeds the cost-minimizing ratio. A special case arises when $\theta = 1$. In this case, the [N-R] input ratio is cost-minimizing, and the [S-R] input ratio exceeds it.

2.3 Equilibrium Analysis

The main purpose of this section is to show the effect of strategic interaction on the equilibrium in the allowance market. This section extends the framework of Section *2.2* to analyze the strategic interaction of two dominant firms.[23] It compares equilibria with and without strategic interaction and examines the implications for efficiency.

This section develops a "nonstrategic reaction function" to illustrate the interaction between the dominant firms' allowance use. This *contrived* reaction function serves as a benchmark for comparison with the strategic reaction function. The relationship between these two reaction functions provides qualitative information about the characteristics of equilibrium behavior by the dominant firms.

In this context, the nonstrategic case is the appropriate benchmark. In the nonstrategic setting, the two dominant firms do not behave strategically and take the price of allowances as given. A dominant firm believes that it cannot affect the market price of allowances through changes in its own demand. A dominant firm in this setting, however, is large enough to affect the market price through changes in its demand *regardless of its beliefs*.[24] The equilibrium setting that captures this effect on market price is characterized in Section 2.8 (see also Figure *2-2*).

The nonstrategic reaction function, $l_1(l_2)$, gives the relationship between the allowance price and allowance use, given the firm is *not* behaving strategically. The function is downward-sloping because a change in firm 2's allowance demand affects firm 1's allowance demand through the price. For example, assume that for some exogenous reason, perhaps technological, firm 2 demands more allowances. The price of allowances rises, given firm 1's demand. Firm 1 observes the price change and then reoptimizes, leading to a decrease in its demand.

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[23] The results are qualitatively the same for multiple strategic players.

[24] As in the optimization section, firm 1 is the representative firm.

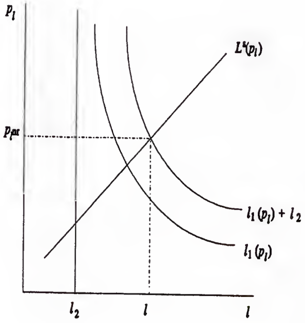

Figure *2-2*: Nonstrategic Equilibrium

How do the nonstrategic reaction function and the strategic one relate? The first order conditions for the two cases, (*A1.1-A1.*7) and (*A2.1-A2.*7), provide the necessary insight. The two sets of conditions have the same form, except for equations (*A1.4*) and (*A2.4*), the expressions for the shadow price of emissions. These two first order conditions are identical if there is a value of l_1, l^*_1, such that

$$(11)\quad p'_l\left[\frac{r(1-\lambda)(L_1-l_1^*) + \lambda(s-r)\theta l_1^*}{r}\right] = 0 .$$

The two *sets* of first order conditions have the same solution at l^*_1 ; therefore, the nonstrategic and strategic reaction functions must coincide at this point.[25] Comparative statics determine the position of the strategic reaction function *relative to* the nonstrategic reaction function for all values of l_1 other than $l_1 = l^*_1$. A parameterization combines the nonstrategic rate-of-return and the strategic rate-of-return problems into a single problem.

Lemma 3: *Let γ be a parameter that describes strategic behavior: if $\gamma = 0$ firm behavior is nonstrategic, and if $\gamma = 1$ firm behavior is strategic. Treating γ as a continuous variable, as γ varies from 0 to 1:*

(i) $\frac{\partial l}{\partial \gamma} > 0$ *if a firm is a seller or a weak buyer, and*

(ii) $\frac{\partial l}{\partial \gamma} < 0$ *if a firm is a strong buyer .*

The depiction of both nonstrategic and strategic reaction functions on the same graph, in l_1-l_2 space, is helpful but purely expositional (see Figure *2-3*). The purpose of depicting the nonstrategic and strategic functions in the same space is the use of the nonstrategic reaction function as a benchmark.

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[25] Note that l^*_1 depends on λ from the strategic case.

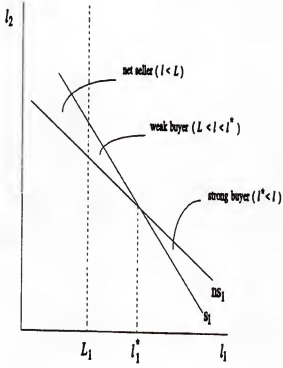

Figure *2-3*: Reaction Functions

In equilibrium, dominant firm interaction yields three general cases: (*i*) both firms are net sellers; (*ii*) both firms are net buyers; (*iii*) one firm is a net seller, and one firm is a net buyer. The possibility of two types of buyers expands the possibilities to nine different cases. These cases divide the l_1-l_2 space into nine regions, and the combination of firm types determines the region in which the firms' reaction functions intersect (see Figure *2-4*).[26] For each firm *i*, $i = 1,2$, l_i falls within one of three possible ranges: (*i*) $l_i < L_i$, (*ii*) $L_i < l_i < l^*_I$ and (*iii*) $l^*_I < l_i$.

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[26] Cases F, G, and H are redundant because each replicates a previous case with the only difference being the reversal of firm types.

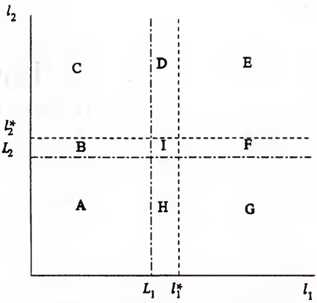

Figure *2-4*: Combinations of Firm Types

The strategic incentives of each type are relevant to the nine cases. A seller overutilizes allowances to raise the market price and uses more allowances relative to the [N-R] case. A strong buyer underutilizes allowances to lower their price and uses fewer allowances relative to the [N-R] case. A weak buyer acts like a seller and overutilizes allowances as well. The six cases below describe the equilibrium effects of strategic behavior:

(*i*) case A - seller, seller (see Figure *2-5*)

With two dominant sellers in the market, their total allowance use (l_1+l_2) increases unambiguously if $|\partial l_1/\partial l_2| > 1$. A decrease in allowance use by both firms cannot occur. The fact that total allowance use increases and both firms are sellers implies that both sellers sell fewer permits in a strategic equilibrium. The volume of trade decreases relative to the nonstrategic equilibrium.

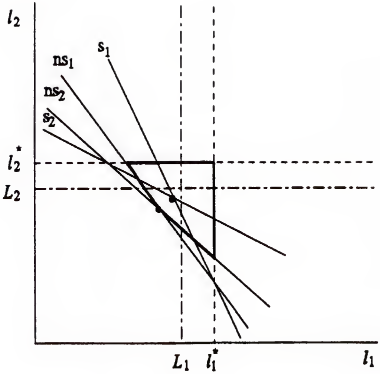

Figure *2-5*: Case A - Two Dominant Sellers

(*ii*) case B - seller, weak buyer

The total allowance use of a dominant seller and a dominant weak buyer increases unambiguously. The effect on trading volume, however, is ambiguous because the direction of change in individual firm allowance use is indeterminate.

(*iii*) case C - seller, strong buyer

With a dominant seller and a dominant strong buyer, the direction of change in their total allowance use is ambiguous. The fact that the seller sells fewer permits and the strong buyer buys fewer permits implies that the volume of trade decreases relative to the nonstrategic equilibrium.

(*iv*) case D - weak buyer, strong buyer

The interaction of a dominant weak buyer and a dominant strong buyer implies that the change in total allowance use is ambiguous because the weak buyer uses more permits, and the strong buyer uses fewer permits. The trading volume is ambiguous because the weak buyer buys more permits, and the strong buyer buys fewer permits.

(*v*) case E - strong buyer, strong buyer (see Figure *2-6*)

With two strong buyers in the market, their total allowance use decreases unambiguously if $|\partial l_1/\partial l_2| > 1$. An increase in allowance use by both firms cannot occur. Since total allowance use decreases and both firms are strong buyers, the volume of trade decreases relative to the nonstrategic equilibrium.

(*vi*) case I - weak buyer, weak buyer

With two dominant weak buyers in the market, their total allowance use increases unambiguously if $|\partial l_1/\partial l_2| > 1$. Since total allowance use increases and both firms are weak buyers, the volume of trade increases relative to the nonstrategic equilibrium.

Theorem 4: *In the absence of weak buyers (omitting cases B, D, and I), trading volume between dominant firms in the strategic equilibrium decreases unambiguously relative to trading volume in the nonstrategic equilibrium.*

The implication of this analysis is that allowance trading volume is predictable *unless* weak buyers are present. This result occurs because strategic incentives induce net sellers to use more allowances and net (strong) buyers to buy fewer allowances. The combination of sellers that sell less and (strong) buyers that buy fewer permits ensures a lower volume of trade in the allowance market.

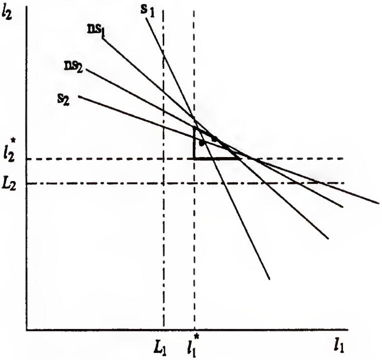

Figure *2-6*: Case E - Two Dominant Strong Buyers

Table *2-1* summarizes these six cases:

Table *2-1*: Effects of Strategic Behavior

Case	Δl_1	Δl_2	$\Delta(l_1+l_2)$	Δ trdg vol.
A	?	?	+	-
B	?	?	+	?
C	+	-	?	-
D	+	-	?	?
E	?	?	-	-
I	?	?	+	+

2.4 Alternative Rate Base Assumptions

One alternative rate base assumption relates to the determination of an appropriate capitalized allowance value. A capitalized value of p_l/r is the economically defensible value for inclusion in the rate base. The problem is that the regulator does not know the firm's cost of capital, r. The regulator's allowed return of s represents its best approximation of r. Although the capitalized value should enter the rate base as p_l/s, this model uses p_l/r instead. This approach allows for the correct economic value to enter the rate base and is consistent with the models used by Coggins and Smith (1993) and Rose *et al.* (1992). Although this approach generates the strong buyer -weak buyer dichotomy, this distinction will always exist *unless* the capitalized value is *exactly* p_l/s. The use of p_l/s in place of p_l/r as the capitalized value in the rate base does not change the qualitative results.[27]

The second alternative rate base assumption relates to the treatment of the initial endowment (L). In the model, the firm's endowment does not appear explicitly in the rate base. This exclusion is economically justifiable because any endowment is a cost-free asset to the firm. A possible objection to this treatment may arise if a regulator wants to

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[27] With p_l/s in the rate base, the [N-R] and [S-R] input ratios respectively are

$$\left(\frac{-\partial h}{\partial a}\right)^{NR} = \frac{r - \lambda s}{(1 - \lambda)p_l} \quad and \quad \left(\frac{-\partial h}{\partial a}\right)^{SR} = \frac{r - \lambda s}{(1 - \lambda)[p_l + p_l^{\prime}(l_1 - L_1)]} \, .$$

The [N-R] ratio will not be cost-minimizing because it is less than r/p_l. The [S-R] ratio will be greater (less than) the [N-R] ratio if the firm is a net seller (net buyer).

include a proportion of the endowment in a firm's rate base to induce it to use the asset prudently. The inclusion of a proportion of the endowment in the rate base, although justifiable, does not affect significantly the analysis because a firm does not choose its endowment.[28]

2.5 Conclusion

Without market power in the emissions permit market, a PUC's asymmetric treatment of abatement capital and emissions permits distorts cost-minimizing behavior in emissions reduction. The tendency of PUCs to disallow permits but to fully include abatement capital in a utility's rate base introduces a distortion in the firm's input choice for emissions reduction.

This rate base effect is not the only effect that may influence a firm's decision-making with respect to environmental compliance. With the introduction of market power, utilities possess strategic incentives to manipulate the permit price. These incentives induce a firm to make a more or less cost-minimizing choice of inputs to reduce emissions, depending on whether it is a net seller or a net buyer of permits.

A dominant utility's strategic behavior not only affects the value of its net sales or net purchases of permits but also affects the asset value of permits that are allowed in its rate base. With respect to the asset value, all utilities have the incentive to raise the permit price strategically since this price enters the rate base directly. This incentive reinforces a seller's motive to obtain a higher price for its net sales of permits. For a net buyer, this incentive opposes its motive to obtain a lower price for its net purchases of permits. If the buyer is a large user of permits, then this latter wealth effect dominates the first effect, and the firm's net strategic incentive is to decrease the price strategically. For a small purchaser (weak buyer) of permits, the higher asset value in the rate base exceeds the firm's savings on permit purchases (from a lower price), and the firm's net strategic incentive is to increase the permit price strategically. The paradox of this result is that a weak net buyer of permits wants a higher market price for permits.

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[28] The fraction (θ) of used allowances enters the rate base. This capital implicitly includes a firm's entire endowment if the firm is a net buyer and a fraction of the endowment if the firm is a net seller. In either case, a firm is allowed to earn a return *only on used allowances*. The fact that a buyer's allowance use fully consumes its endowment and a net seller's allowance use does not fully consume its endowment creates the disparity. (A net seller should not be allowed to earn a return on (L - l) allowances because its revenue from the sale of allowances enters its objective directly).

The equilibrium analysis provides several insights. It confirms the results in the firm optimization section with respect to the effects of strategic behavior and the effect on input decision biases. In a strategic equilibrium relative to a nonstrategic equilibrium benchmark case, a tendency exists for the trading volume of emissions allowances to decrease. In the absence of weak buyers, the trading volume decreases unambiguously. The strategic effects imply that sellers sell fewer permits, and buyers buy fewer permits in the allowance market.

One implication from this analysis is that with or without strategic behavior in the permit market, the market's attainment of a specific level of emissions reduction at minimum cost may be problematic. With a competitive permit market, asymmetric regulatory treatment of emissions reductions options introduces a bias in a firm's choice between abatement and permits to achieve compliance. Given PUCs' current rate making position on abatement capital, only the full *inclusion* of permits in the rate base fully eliminates the distortion. With strategic behavior in the market, any treatment other than full *exclusion* of permits from the rate base provides a strategic distortion. As a result, if market power is not likely then full inclusion of permits in the rate base gives a cost-minimizing pollution reduction decision. If market power is present, then any inclusion opens a rate base channel for strategic effects. The result is interaction between utilities' rate base incentives and strategic incentives.

2.6 The [N-R] Solution

The program and Kuhn-Tucker conditions for the nonstrategic regulated case [N-R] are:

$$\max_{\{x,k,a,l_1\}} \quad \pi = p(q)q - wx - r(k+a) + p_l(L_1 - l_1)$$

$$\begin{aligned} s.t. \quad & q \le f(x,k) \\ & p(q)q - wx + p_l[L_1 - l_1(1-\theta)] \le s\left(k + a + \frac{\theta p_l l_1}{r}\right) \\ & h(f(x,k),a) \le l_1 \end{aligned}$$

$(A1)$

(1) $$\frac{\partial \mathcal{L}}{\partial x} = \frac{\partial f}{\partial x}\left[\left(\frac{\partial p}{\partial f} f(x,k) + p(f(x,k))\right)(1-\lambda) - \mu\frac{\partial h}{\partial f}\right] - w(1-\lambda) \le 0$$

(1′) $$\left(\frac{\partial \mathcal{L}}{\partial x}\right) x = 0$$

(2) $$\frac{\partial \mathcal{L}}{\partial k} = \frac{\partial f}{\partial k}\left[\left(\frac{\partial p}{\partial f} f(x,k) + p(f(x,k))\right)(1-\lambda) - \mu\frac{\partial h}{\partial f}\right] + \lambda s - r \le 0$$

(2′) $$\left(\frac{\partial \mathcal{L}}{\partial k}\right) k = 0$$

$$(3)\quad \frac{\partial \mathcal{L}}{\partial a} = r - \lambda s + \mu \frac{\partial h}{\partial a} \leq 0$$

$$(3')\quad \left(\frac{\partial \mathcal{L}}{\partial a}\right) a = 0$$

$$(4)\quad \frac{\partial \mathcal{L}}{\partial l} = \mu - p_l \left[\frac{r(1-\lambda) - \lambda(s-r)\theta}{r}\right] \leq 0$$

$$(4')\quad \left(\frac{\partial \mathcal{L}}{\partial l}\right) l = 0$$

$$(5)\quad \frac{\partial \mathcal{L}}{\partial \lambda} = (s-r)\left(k + a + \frac{\theta p_l l_1}{r}\right) - p(f(x,k))f(x,k) + wx + r(k+a) - p_l(L_1 - l_1) \geq 0$$

$$(5')\quad \left(\frac{\partial \mathcal{L}}{\partial \lambda}\right) \lambda = 0$$

$$(6)\quad \frac{\partial \mathcal{L}}{\partial \mu} = l_1 - h(f(x,k),a) \geq 0$$

$$(6')\quad \left(\frac{\partial \mathcal{L}}{\partial \mu}\right) \mu = 0$$

$$(7)\quad x \geq 0,\ k \geq 0,\ a \geq 0,\ l \geq 0,\ \lambda \geq 0,\ \mu \geq 0$$

The assumption of an interior solution means $x > 0$, $k > 0$, $a > 0$, and $l_1 > 0$. As a result, the complementary slackness conditions (*1′*), (*2′*), (*3′*), and (*4′*) imply that (*1*), (*2*), (*3*), and (*4*) are binding equalities. The interesting case is the one in which (*5*) and (*6*) are binding constraints.

(*i*) If $\lambda > 0$ then (*5*) binds:

a) if $\lambda > 1$, then from (*4*) the second (bracketed) term is negative and so $\mu < 0$; however, $\mu \geq 0$ by assumption, so a contradiction exists, and it cannot be that $\lambda > 1$.

b) if $\lambda = 1$, then from (*1*), $-\mu h_q f_x = 0$; this implies $\mu = 0$ since $h_q > 0$ and $f_x > 0$; from (*4*), $\lambda = 1$ and $\mu = 0$ imply $s = r$; this contradicts the assumption that $s > r$.

c) if $\lambda = 0$, then (*5*) will not necessarily bind at the solution; if it is non-binding, then the problem collapses into the unregulated case; therefore, assume $\lambda \neq 0$.

d) combining *a*), *b*), and *c*), the result is $0 < \lambda < 1$.

(*ii*) If $\mu > 0$ then (*6*) binds:

a) if $\mu = 0$, then from (*3*), $r - \lambda s = 0$; but from (*2*), $r - \lambda s > 0$; this is a contradiction; therefore, $\mu \neq 0$.

b) since $\mu \geq 0$ by assumption, then $\mu > 0$. ▪

2.7 The [S-R] Solution

The program and Kuhn-Tucker conditions for the strategic regulated case are:

$$\max_{\{x,k,a,l_1\}} \quad \pi = p(q)q - wx - r(k+a) + p_l[(l_1,l_2)](L_1 - l_1)$$

$$\begin{aligned} s.t. \qquad & p(q)q - wx + p_l[(l_1,l_2)][L_1 - l_1(1-\theta)] \leq s\left(k + a + \frac{\theta p_l[(l_1,l_2)]l_1}{r}\right) \\ & h(f(x,k),a) \leq l_1 \\ & q \leq f(x,k) \end{aligned}$$

(*A2*)

$$(1) \quad \frac{\partial \mathcal{L}}{\partial x} = \frac{\partial f}{\partial x}\left[\left(\frac{\partial p}{\partial f}f(x,k) + p(f(x,k))\right)(1-\lambda) - \mu\frac{\partial h}{\partial f}\right] - w\;(1-\lambda) = 0$$

$$(2) \quad \frac{\partial \mathcal{L}}{\partial k} = \frac{\partial f}{\partial k}\left[\left(\frac{\partial p}{\partial f}f(x,k) + p(f(x,k))\right)(1-\lambda) - \mu\frac{\partial h}{\partial f}\right] + \lambda s - r = 0$$

$$(3) \quad \frac{\partial \mathcal{L}}{\partial a} = r - \lambda s + \mu\frac{\partial h}{\partial a} = 0$$

$$(4) \quad \frac{\partial \mathcal{L}}{\partial l} = \mu - p_l[(l_1,l_2)]\left[\frac{r(1-\lambda) - \lambda(s-r)\theta}{r}\right] + p'_l[(l_1,l_2)]\left[\frac{r(1-\lambda)(L_1 - l_1) + \lambda(s-r)\theta l_1}{r}\right] = 0$$

$$(5)\quad \frac{\partial \mathcal{L}}{\partial \lambda} = (s-r)\left(k + a + \frac{\theta p_l[(l_1,l_2)]l_1}{r} \right) - p(f(x,k))f(x,k) + wx$$
$$+ r(k+a) - p_l[(l_1,l_2)](L_1 - l_1) = 0$$

$$(6)\quad \frac{\partial \mathcal{L}}{\partial \mu} = l_1 - h(f(x,k),a) = 0$$

$$(7)\quad x>0,\ k>0,\ a>0,\ l_1>0,\ \lambda>0,\ \mu>0$$

In the conditions above, $p^{sr}{}_l = p_l[(l_1,l_2)]$ is the strategic price as a function of both l_1 and l_2. Also, $p_l'[\bullet]$ is a function of the same two elements; however, it is the derivative with respect to l_1 since firm 1 is representative.

2.8 The [N-R] Equilibrium

The nonstrategic equilibrium setting is characterized by the following: (*i*) an upward-sloping supply of allowances, $L^S(p_l)$, given by $L^S(p_l) = \bar{L} - l^d{}_f$; (*ii*) the representative firm's demand, $l_1(p_l)$; (*iii*) the other dominant firm's (firm 2's) level of allowance use, l_2. Each level of l_2 generates an (l_1,l_2) combination on the supply function, $L^S(p_l)$, such that $L^S(p_l) = l_1(p_l) + l_2$ (see Figure *2-2*). The equilibrium price in the market, given what firm 2 does, is

(*A3*) $p_l^{nr} \equiv \bar{p}(l_2) \equiv p_l(l_1(p_l) + l_2)$.

This expression is solvable for the nonstrategic reaction function, $l_1(l_2)$.

2.9 Proofs

Proof of Theorem 1

The distortion in the firm's production decision (*8a*) is obtained by combining (*A1.1*) and (*A1.2*) to get

$$(A4)\quad \frac{f_k}{f_x} = \frac{r}{w} - \frac{\lambda(s-r)}{w(1-\lambda)} = \frac{r-\lambda s}{w(1-\lambda)} < \frac{r}{w}$$

$$\text{since}\quad \frac{\lambda(s-r)}{w(1-\lambda)} > 0\ .$$

The distortion in the compliance decision (*8b*) is obtained by rewriting (*A1.1*) as

$$(A5)\quad R'(q) = \frac{\partial h}{\partial q}\left(\frac{\mu}{1-\lambda}\right) + \frac{r-\lambda s}{f_k(1-\lambda)}\ .$$

Use (*A1.2*) and (*A1.3*) to get

$$(A6)\quad R'(q) = \left(\frac{\mu}{1-\lambda}\right)\left(h_q - \frac{1}{f_k}h_a\right)$$

Combine (*A5*) and (*A6*) to get

$$(A7)\quad \frac{-\partial h}{\partial a} = \frac{r}{p_l}\left[\frac{r-\lambda s}{r(1-\lambda)-\lambda(s-r)\theta}\right] < \frac{r}{p_l}.$$

In this expression, if $0 \le \theta < 1$, the bracketed term is less than one because $|r-\lambda s| < |r(1-\lambda) - \theta(s-r)\lambda|$. If $\theta = 1$, then the bracketed expression equals one, and the input choice is efficient. ▪

Proof of Lemma 2

Let the fringe inverse demand curve cross the perfectly inelastic supply such that for $l_f = \bar{L}$, then $p_l = p^*_l$. Let L_1 and L_2 represent the initial endowments (respectively) of the dominant firms. Also, l_1 and l_2 are the number of allowances held or demanded by the dominant firms. The competitive fringe has aggregate endowment $L_f = \sum^n_{i=3} L_i$ and demands $l_f = \sum^n_{i=3} l_i$ allowances. This information implies the identity

(*A8*) $\bar{L} \equiv L_1 + L_2 + L_f$.

Also, it must be the case that in equilibrium

(*A9*) $\bar{L} = l_1 + l_2 + l_f$.

Given these conditions, it follows that the dominant firms face the inverse supply curve

(*A10*) $p^f_l(l_f) = p_l(\bar{L} - l_f) = p_l[(l_1 + l_2)]$. ▪

Proof of Theorem 2

Equation (*A2.1*) may be expressed as

$$(A11) \quad R'(q) = \frac{\partial h}{\partial q}\left(\frac{\mu}{1-\lambda}\right) + \frac{r-\lambda s}{f_k(1-\lambda)} .$$

A combination of (*A2.2*) and (*A2.3*) gives

$$(A12) \quad R'(q) = \left(\frac{\mu}{1-\lambda}\right)\left(h_q - \frac{1}{f_k} h_a\right) .$$

The use of (*A11*) and (*A12*) together, along with a substitution for μ, yields equation (*9*).▪

Proof of Theorem 3a

The input ratio for the [S-R] case is

$$(A13) \quad \left(-\frac{\partial h}{\partial a}\right)^{SR} = \left[\frac{r(r-\lambda s)}{p_l[r(1-\lambda)-\lambda(s-r)\theta] - p_l'[r(1-\lambda)(L_1-l_1)+\lambda(s-r)\theta l_1]}\right] .$$

For a net seller, since $L_1 - l_1 > 0$, this ratio is greater than the [N-R] input ratio since $p_l' > 0$ by assumption; *i.e.*,

$$(A14) \quad \left[\frac{r(r-\lambda s)}{p_l[r(1-\lambda)-\lambda(s-r)\theta] - p_l'[r(1-\lambda)(L_1-l_1)+\lambda(s-r)\theta l_1]}\right] > \frac{r}{p_l}\left[\frac{r-\lambda s}{r(1-\lambda)-\lambda(s-r)\theta}\right] .$$

The condition in property (*i*) can be rewritten as

$$(A15) \quad \frac{r}{p_l} > \left[\frac{r(r-\lambda s)}{p_l[r(1-\lambda)-\lambda(s-r)\theta] - p_l'[r(1-\lambda)(L_1-l_1)+\lambda(s-r)\theta l_1]}\right] .$$

It is shown above that the [S-R] ratio is greater than the [N-R] ratio. As long as *(A15)* is satisfied, the [S-R] input ratio exceeds the [N-R] ratio but is less than the cost efficient ratio. This fact and the convexity of the emissions isoquant guarantee that this case yields a more cost-minimizing input combination. For property *(i)*, it must be true that $0 \le \theta < 1$; otherwise (for $\theta = 1$), the condition in property *(i)* is not satisfied.

The condition in property *(ii)* implies

$$(A16) \left[\frac{r(r-\lambda s)}{p_l[r(1-\lambda)-\lambda(s-r)\theta] - p_l'[r(1-\lambda)(L_1-l_1)+\lambda(s-r)\theta l_1]}\right] > \frac{r}{p_l} > \frac{r}{p_l}\left[\frac{r-\lambda s}{r(1-\lambda)-\lambda(s-r)\theta}\right]$$

In graphical terms, the [S-R] ratio lies on the other side of the tangency point between the emissions isoquant and the abatement-allowance expenditure line. Further comparison requires more quantitative information. ▪

Proof of Theorem 3b

First, consider property *(i)*. For a net buyer ($L_1 - l_1 < 0$) that is also a strong buyer, it must be the case that $|r(1-\lambda)(L_1-l_1)| > \lambda(s-r)\theta l_1$. As a result, the inequality in *(A14)* reverses because the bracketed expression multiplying p_l' in the [S-R] input ratio is negative. This result holds for any θ, $0 \le \theta \le 1$. For a net buyer ($L_1 - l_1 < 0$) that is also a weak buyer, that is, $|r(1-\lambda)(L_1-l_1)| < \lambda(s-r)\theta l_1$, *(A14)* holds, and there are two possible cases. The proof of properties *(iia)* and *(iib)* exactly parallels the proof of properties *(i)* and *(ii)* in *Theorem 3a*. ▪

Proof of Lemma 3

A combination of (*A1.4*) and (*A2.4*) yields

$$(A17)\quad -\ (\gamma)\left(p_l[(l_1,l_2)]\left[(1-\lambda)-\frac{\lambda(s-r)\theta}{r}\right]-p'_l[(l_1,l_2)]\left[(1-\lambda)(L_1-l_1)+\frac{\lambda(s-r)\theta l_1}{r}\right]\right)$$
$$-\ (1-\gamma)\left(\overline{p}_l(l_2)(1-\lambda)-\overline{p}_l(l_2)\left[\frac{\lambda(s-r)\theta}{r}\right]\right)+\mu\ =\ 0$$

where the price in the [N-R] regime is $p^{nr}{}_l=\overline{p}_l(l_2)$, and the price in the [S-R] regime is $p^{sr}{}_l=p_l[(l_1,l_2)]$. Let $\gamma = 0$ define firm behavior as nonstrategic, and let $\gamma = 1$ define firm behavior as strategic. The relation of the nonstrategic reaction function to the strategic reaction function is obtainable by finding the change in a firm's allowance use as γ varies, that is, the comparative static derivative, $\partial l_1/\partial\gamma$, taken at a point that lies ϵ from the nonstrategic reaction function. The sign of $\partial l_1/\partial\gamma$ is the subject of interest. The relevant first order conditions are (*A2.1-A2.6*), where (*A2.4*) is replaced with the revised (parameterized) condition given by (*A17*). Assume that the program that corresponds to this set of revised conditions satisfies the second order sufficiency conditions. Let $|H|$ represent the determinant of the bordered Hessian for this program:

$$H\ =\ \begin{bmatrix} L_{xx} & L_{xk} & L_{xa} & L_{xl} & L_{x\mu} & L_{x\lambda} \\ L_{kx} & L_{kk} & L_{ka} & L_{kl} & L_{k\mu} & L_{k\lambda} \\ L_{ax} & L_{ak} & L_{aa} & L_{al} & L_{a\mu} & L_{a\lambda} \\ L_{lx} & L_{lk} & L_{la} & L_{ll} & L_{l\mu} & L_{l\lambda} \\ L_{\mu x} & L_{\mu k} & L_{\mu a} & L_{\mu l} & L_{\mu\mu} & L_{\mu\lambda} \\ L_{\lambda x} & L_{\lambda k} & L_{\lambda a} & L_{\lambda l} & L_{\lambda\mu} & L_{\lambda\lambda} \end{bmatrix}.$$

Using comparative statics analysis,

$$(A18)\quad \frac{\partial l_1}{\partial \gamma} = \frac{-L_{l\gamma}\,|H_{44}|}{|H|}\ ,$$

where the subscripts on $|H_{44}|$ indicate the row and column (respectively) deleted from the bordered Hessian to form the appropriate principal minor, and

$$\begin{aligned}(A19)\, L_{l\gamma} = &\left(\bar{p}_l(l_2)(1-\lambda) - \bar{p}_l(l_2)\left[\frac{\lambda(s-r)\theta}{r}\right]\right)\\ &-\left(p_l(l_1+l_2)(1-\lambda) - p_l(l_1+l_2)\left[\frac{\lambda(s-r)\theta}{r}\right] - p'_l(l_1+l_2)\left[(1-\lambda)(L_1-l_1) + \frac{\lambda(s-r)\theta l_1}{r}\right]\right)\end{aligned}$$

Sign $[\partial l_1/\partial\gamma]|_{\gamma=1}$ = sign $[L_{l\gamma}]$ since from the second order conditions, sign $[-\,|H_{44}|/|H|] > 0$. For an ϵ deviation from the nonstrategic reaction function, $p^{nr}_l = p^{sr}_l$; *i.e.*, $\bar{p}_l(l_2) = p_l(l_1+l_2)$. Therefore,

$$(A20)\quad sign\left[\frac{\partial l_1}{\partial\gamma}\right]_{\gamma=1} = sign\left\{p'_l(l_1+l_2)\left[(1-\lambda)(L_1-l_1) + \frac{\lambda(s-r)\theta l_1}{r}\right]\right\}.$$

From (*A20*), $[\partial l_1/\partial\gamma]_{\gamma=1} > 0$ if *i)* $L_1 > l_1$ or *ii)* $L_1 < l_1$ and $|(1-\lambda)(L_1-l_1)| < [\lambda(s-r)\theta l_1/r]$; and $[\partial l_1/\partial\gamma]_{\gamma=1} < 0$ if *iii)* $L_1 < l_1$ and $|(1-\lambda)(L_1-l_1)| > [\lambda(s-r)\theta l_1/r]$. ▪

Proof of Theorem 4

The proof is graphical and follows directly from the use of Figure *2-4* to depict cases A, C, and E. These cases generate the relevant information in Table *2-1*.▪

CHAPTER 3
POLLUTION PERMIT BANKING AS AN INSTRUMENT FOR STRATEGIC ENTRY DETERRENCE

3.1 Introduction

Markets for tradeable pollution rights are an increasingly popular alternative to traditional methods of regulating environmental quality. The primary advantage of using an emissions permit system is that under ideal conditions it facilitates the attainment of a specific emissions target at minimum cost. This approach accounts for the fact that pollution abatement costs differ across firms. Those firms with relatively expensive emissions control technologies will have the incentive to buy allowances while firms with relatively inexpensive technologies will have the incentive to sell allowances.[1] An important feature of this mechanism is the flexibility that it gives polluting firms in their choice of compliance options.

In general, a regulator determines an aggregate quantity of pollution emissions that is allowable in a given year. It then allocates or sells through an auction a quantity of permits such that the total quantity of emissions equals this cap.[2] An allowance is a certificate that authorizes the owner to emit a unit of pollutant in the current year or any subsequent year. In this system, environmental compliance requires that firms releasing pollution into the atmosphere possess an emission allowance or permit for each unit of emitted pollutant. At the end of each year, therefore, a polluting firm must possess a quantity of allowances equal to or greater than its annual emissions. Failure to satisfy this requirement incurs a major penalty for noncompliance.

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[1] Montgomery (1972) first demonstrated this result.

[2] In an emissions permit system (EPS), the regulator denominates permits in units of pollutant emitted; that is, one permit gives the owner the right to emit one ton of pollutant into the atmosphere. The EPS implies that trades between firms are at a one-to-one rate.

The best known public policy application of this idea is the Clean Air Act Amendments' Title IV implementation of a market in sulfur dioxide emissions rights.[3] THE CAAA enable firms to acquire these permits through either endowments, auctions, and/or from the permit market.[4] The Environmental Protection Agency (EPA) endows allowances annually to affected units and allocated the first endowments for Phase I in 1995.[5] For Phase II, which begins in 2000, the EPA will reduce the annual limit on emissions and therefore, the number of permits for these allocations. It will also impose emissions limits on smaller, cleaner generating units. Allowances are fully tradeable commodities - they may be purchased, sold, or banked by any corporation, government entity, environmental group, other interested party, or private citizen.

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[3] The CAAA environmental regulations generally apply to investor-owned electric utilities (IOUs) that generate electricity with coal-fired units.

[4] Provisions make additional (reserve) allowances available for the installation of qualifying Phase I technology, implementation of customer-oriented conservation measures or renewable energy generation, and for EPA auctions.

[5] An "affected" unit is a generating unit that emits more than the legal sulfur dioxide limit. The CAAA regulation, therefore, is a binding constraint on affected units. The EPA allocates Phase I allowances to each affected unit at an emissions rate of 2.5 SO_2 lbs./mm Btu of heat input, multiplied by the unit's baseline mmBtu (average fossil fuel consumption from 1985 to 1987).

An increasingly important aspect of this market is *allowance banking*, which enables firms to use allowances in future years.[6] Consequently, allowance banking provides additional flexibility for firms seeking the least-cost compliance option. Although intertemporal allowance trading is an important topic that is largely absent from the literature, several authors have examined firm incentives for allowance banking. Cronshaw and Kruse (1996) used a discrete time model to show that firms allocate emissions across time periods in order to minimize the present value of abatement costs.[7] Kling and Rubin (1997) developed an optimal control model to examine firm incentives to bank and borrow allowances and compared firm choices of emission and output streams to the social optimum. They found that the output and emissions paths of individual firms differ from the socially optimal paths because firms allocate more emissions to the present period relative to the social optimum.[8]

The key issue is utilities' incentives for banking. From a financial perspective, there is no reason to expect permit banking. Banked permits are assets that earn no interest. Firms only earn a return from allowance banking if the rate of increase in the expected price of permits exceeds the interest rate. EPA data show, however, that to date utilities are significantly over-controlling their emissions and banking excess permits. In 1995, the EPA issued 8.7 million sulfur dioxide allowances, but total emissions were only 5.3 million tons. Allowance deductions for compliance purposes were sixty-one percent of total allowances issued; therefore, utilities banked 3.4 million allowances or thirty-nine percent of the total. Similarly, in 1996, the EPA issued 8.3 million allowances, but total emissions were only 5.4 million tons. Banked allowances comprised thirty-five percent of total allowances issued that year.[9]

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[6] The CAAA prohibit reverse banking or borrowing.

[7] This result depends on a competitive allowance market.

[8] This result arises because firms treat the stock of permits as a fixed endowment and discount the future when allocating this stock. See Kling and Rubin (1997).

One possible explanation is that firms are capitalizing on exogenous changes in the markets of related goods.[10] For example, the availability of low sulfur coal as a low cost compliance option implies that fuel-switching incentives have enabled utilities to reduce emissions and to bank more allowances. A second possibility is that firms are anticipating the implementation of a more stringent emissions cap with the start of Phase II in the year 2000. The EPA will issue fewer allowances and impose tighter limits on Phase I plants.[11] The EPA will also place emissions limits on relatively cleaner units as well.

A third possibility is that firms are banking allowances for the purpose of future strategic entry deterrence. In this context, permit banking may signal a firm's commitment to maintain output levels. The purchase of permits today essentially represents an investment in capacity for future production. Additional output creates more pollution, and a firm must either increase its abatement or acquire more permits to achieve environmental compliance.

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[9] See EPA Compliance Reports (1997).

[10] See Burtraw (1996) for a discussion of these cost-saving opportunities.

[11] The EPA will allocate allowances at a revised rate of 1.2 SO_2 lbs./mmBtu of heat input multiplied by the unit's baseline.

This capacity interpretation parallels the work of Dixit (1980) and Brander and Spencer (1981). Dixit analyzed the effect of an incumbent firm's unalterable choice of investment on its post-entry marginal cost and therefore, on the post-entry equilibrium. He concluded that this investment alters the initial conditions of the post-entry game given a fixed set of rules. Brander and Spencer (1981) examined firms' simultaneous use of strategic cost reduction to gain an advantage in an output game.[12] In their two-stage duopoly model, strategic cost reduction is a form of commitment that enables firms to affect the industry equilibrium outcome.

The possibility that permit banking is a form of strategic commitment is especially important because the movement toward competition in the U.S. electricity industry is underway. The transition to competitive markets involves the functional unbundling of generation, transmission, and distribution services. Although the outcome of restructuring is uncertain, the generation stage will likely be competitive at both the wholesale and retail levels. Federal law currently allows customer choice at the wholesale level. The Energy Policy Act of 1992 (EPAct) permits wholesale customers, the independent distribution companies, to choose a supplier and mandates that utilities transmit power across their territories to facilitate this choice.[13]

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[12] In their model, strategic cost reduction takes the form of research and development. They did not model any formal distinction between research and development and investment in capital stock.

A complex array of political and economic events have made this transition to competition possible. One of the most important catalysts was the passage of the Public Utilities Regulatory Policy Act of 1978 (PURPA). PURPA spawned the movement toward competition in the generation stage of electricity production. It encouraged energy conservation as well as alternative and more efficient production techniques. These initiatives contributed to technological developments in the electricity industry that made the construction of smaller and less expensive generating units economically feasible. PURPA's long term impact has been the promotion of a new sector of independent generators (called independent power producers or IPPs).[14]

IPPs are non-utility generators that operate to provide power to unaffiliated distribution utilities. They are smaller, unintegrated producers of electricity that utilize natural gas or non-fossil fuels for energy sources. Although IPPs currently supply approximately ten percent of electricity in the U.S., they have accounted for more than fifty percent of new generation capacity since 1990. From 1990 to 1994, utility purchases of electricity from nonutility generators grew approximately eighty percent.[15] The sustained growth of this sector has proved that economies of scale in electricity generation are no longer a valid justification of the monopoly status of generation.

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[13] This activity is known as wholesale wheeling.

[14] Joskow (1989), pp. 125-168.

[15] Independent power producers and qualifying facilities (QFs) are types of non-utility generators. Qualifying facilities are either independent cogenerators or small production facilities (under eighty megawatts) that use a renewable fuel source.

The confluence of competitive restructuring with the recent implementation of incentive-based environmental regulation provides an opportunity for the strategic use of emissions allowances for anticompetitive purposes. The fact that incumbent utilities rely largely on coal-fired generating units for electricity production and that a large number of potential new entrants are cleaner IPP competitors supports this possibility. Allowance banking enables these incumbents to reduce their future production costs and to compete more effectively with prospective entrants for which environmental constraints are not binding.

3.2 Emissions Permits, Banking, and Compliance

The potential use of these property rights as strategic instruments for entry deterrence is analyzed in a two-period model. The setting is a regional market in which a single incumbent firm (an IOU) generates a negative externality as a by-product of its electricity generation. The incumbent sells generated electricity to competitive buyers (distributors) in a downstream market. For simplicity, there exists a single potential entrant (an IPP) that may enter the incumbent's territory in the second period. This potential entrant generates electricity with a clean technology, and its generated electricity is a perfect substitute for the incumbent's electricity output.

Throughout the chapter, capital letters refer to variables associated with the incumbent firm's decisions, and lower-case letters refer to variables associated with the entrant's decisions. Since the incumbent operates in both periods, numerical *superscripts* indicate the relevant period. These superscripts are omitted for the entrant since it makes decisions only in the second period. Finally, *subscripts* indicate partial derivatives. By assumption, all functions are twice continuously differentiable.

In the first period, the incumbent utility is the monopoly producer of generated electricity (Q^1) in a regional market. The incumbent has inverse demand $P(Q^1)$, where $P^1 = P(Q^1)$ is the price in period one. Electricity is nonstorable, and any output is sold in the same period in which it is produced. Total revenue, R^1, for the monopolist is $R^1 = P(Q^1)Q^1$. By assumption, the firm's marginal revenue is decreasing in its own output: $R^i_{QQ} = \partial^2 R^i/\partial Q^i \partial Q^i < 0$, $i = 1, 2$.

The incumbent's technology generates sulfur dioxide emissions as a by-product of its production process, and the firm emits this pollution into the atmosphere. The incumbent may choose to abate some of these emissions. This physical abatement is costly and reflects, for example, the firm's operation of scrubbers. The firm's net emissions function is $E(Q^i, H^i)$ in period i, and its total variable cost is $C^i = C(Q^i, H^i)$, where H^i is physical abatement.

The incumbent must satisfy a *per period* environmental constraint. Its net emissions (gross emissions less any abatement) must be weakly less than its emissions permits *used* (Δ^i). In the first period, these permits are equal to the incumbent's exogenous endowment (L^1) from the regulator less any unused permits (B) it decides to bank. In the second period, these permits are equal to the incumbent's exogenous endowment (L^2) *plus* any banked permits. One assumption throughout the chapter is that it is profitable for the incumbent to produce in both periods; therefore, cases in which the incumbent has an incentive to shut down are not considered. Also, the incumbent cannot bank all of its first period endowment. This assumption implies that a firm's abatement of *all* emissions is prohibitively costly. A final assumption that is consistent with the legal structure of the sulfur dioxide allowance market is that the incumbent cannot borrow allowances. These assumptions are

$$(1a)\quad Q^1 > 0 \quad , \quad Q^2 > 0$$
$$(1b)\quad B : B \in [0, L^1) \quad .$$

For convenience, it is assumed that the per period endowments are equal: $L^1 = L^2 > 0$. This equivalence provides symmetry which makes the analysis more tractable. An inequality of the endowments does not affect the qualitative results. The complete emissions constraints respectively are

$$(2a)\quad E(Q^1, H^1) \leq L^1 - B = \Delta^1$$
$$(2b)\quad E(Q^2, H^2) \leq L^2 + B = \Delta^2 \quad .$$

It is assumed that the second period endowment (L^2) is less than the amount of emissions that occur if the firm uses no abatement in the second period: $L^2 < E(Q^2, 0)$. The assumptions on the emissions function are

$$(2c)\quad \frac{\partial E}{\partial Q^i} > 0 \quad , \quad \frac{\partial E}{\partial H^i} < 0 \quad , \qquad i = 1, 2 .$$

The first inequality in (*2c*) implies that for a fixed level of abatement, increases in output increase the firm's emissions. The second inequality implies that for a fixed level of output, a marginal increase in abatement reduces emissions. The emissions function does not change from the first period to the second period; therefore, an implicit assumption is that abatement technology does not change over time.

The right side of the inequalities in *(2a-2b)* is equivalent to total allowance use in a given period. As a result, the firm's environmental constraint always binds because the incumbent never uses more permits for compliance than necessary. The constraints imply that the amount of abatement undertaken depends on the firm's output, the quantity of banked permits, and the endowment, that is, $H^i = H(Q^i, \Delta^i)$. For the abatement function, $\partial H/\partial Q > 0$ for a constant level of emissions because for a given level of output, an increase in output must be accompanied by an increase in abatement. Also, $\partial H/\partial \Delta < 0$ because for a given level of output, an increase in allowance use implies a decrease in abatement since the two are substitutes.

The firm's cost is a function of its output and abatement. Since L^i is fixed, the firm's variable cost of production is $C^i = \tilde{C}(Q^i, H^i(Q^i, \Delta^i))$. The first order assumptions on the primitives are

$$(3a) \quad \frac{\partial \tilde{C}^i}{\partial Q^i} = \tilde{C}_Q > 0 \quad , \quad \frac{\partial \tilde{C}^i}{\partial H^i} = \tilde{C}_H > 0 \quad .$$

Condition *(3a)* states that the marginal cost of output is positive and that the marginal cost of abatement is positive as well. The second order assumptions are

$$(3b) \quad \frac{\partial^2 \tilde{C}^i}{\partial Q \partial Q} = \tilde{C}_{QQ} > 0 \quad , \quad \frac{\partial^2 \tilde{C}^i}{\partial Q \partial H} = \tilde{C}_{QH} > 0 \quad , \quad \frac{\partial^2 \tilde{C}^i}{\partial H \partial H} = \tilde{C}_{HH} > 0 \quad .$$

The first inequality in *(3b)* states that the marginal cost of production increases at an increasing rate. The second inequality states that the marginal cost of production increases with an increase in abatement. Finally, the third inequality states that the marginal cost of abatement increases at an increasing rate. For the latter, an increase in the firm's current level of abatement increases marginal cost because the firm is attempting to abate more of a fixed level of emissions. The reduced form of this cost function is $C^i = \hat{C}(Q^i, \Delta^i)$. The following first order properties characterize this cost function in both periods:

$$(4a) \quad \frac{\partial \hat{C}^i}{\partial Q^i} = \tilde{C}_Q + \tilde{C}_H \frac{\partial H^i}{\partial Q^i} > 0 \quad , \quad \frac{\partial \hat{C}^i}{\partial \Delta^i} = \tilde{C}_H \frac{\partial H^i}{\partial \Delta^i} < 0 \quad .$$

Given the prior assumptions on the primitives, *(4a)* simply states that the marginal cost of production is positive, and an increase in permit use in the current period decreases current period costs. The second order reduced form properties are

$$\begin{aligned} (4b) \quad \frac{\partial^2 \hat{C}^i}{\partial Q^2} &= \tilde{C}_{QQ} + \tilde{C}_{QH}\frac{\partial H}{\partial Q} + \left[\tilde{C}_{HQ} + \tilde{C}_{HH}\right]\frac{\partial H}{\partial Q} > 0 \\ \frac{\partial^2 \hat{C}^i}{\partial Q\, \partial \Delta} &= \left[\tilde{C}_{QH} + \tilde{C}_{HH}\frac{\partial H}{\partial Q}\right]\frac{\partial H}{\partial \Delta} < 0 \quad . \end{aligned}$$

The marginal cost of output increases with output. Permit use in period *i* lowers marginal cost in period *i*. The rationale for the latter is that with an increase in permit use the firm undertakes less costly abatement activities.

At this point, a translation is useful. Since $\Delta^1 = L^1 - B$ and $\Delta^2 = L^2 + B$, a choice of B determines Δ^i, given the fixed endowment. This translation directly implies $C^i = C(Q^i, B), i = 1,2$. As a result, the firm's cost function embeds the binding per period environmental constraint as well as the firm's decisions about abatement. Applying the translation yields

$$(5a)\quad \frac{\partial C^1}{\partial B} = \frac{-\partial \hat{C}^1}{\partial l^1} \quad and \quad \frac{\partial^2 C^1}{\partial Q^1 \partial B} = \frac{-\partial^2 \hat{C}^1}{\partial Q^1 \partial l^1} \quad .$$

Similarly, the properties for the second period cost function are

$$(5b)\quad \frac{\partial C^2}{\partial B} = \frac{\partial \hat{C}^2}{\partial l^2} \quad and \quad \frac{\partial^2 C^2}{\partial Q^2 \partial B} = \frac{\partial^2 \hat{C}^2}{\partial Q^2 \partial l^2} \quad .$$

Banked permits increase first period total cost ($C^1_B > 0$) and marginal cost ($C^1_{BQ} > 0$). They decrease second period total cost ($C^2_B < 0$) and marginal cost ($C^2_{BQ} < 0$). Also, the total cost in period one increases with B at an increasing rate ($C^1_{BB} > 0$). Also, the total benefit in period two increases with B at a decreasing rate ($C^1_{BB} > 0$). This result arises because in the first period, a further increase in B eventually compels the firm to utilize more expensive abatement technologies in order to achieve a level of abatement that satisfies the emissions constraint. In the second period, banking gives the firm an initially large benefit (cost reduction) as it utilizes permits it previously banked in order to reduce its use of relatively expensive abatement technologies. The incumbent's cost function in period i is strictly globally convex in the variables Q^i and B; that is, the cost function $C^i(Q^i, B)$ satisfies $C^i_{QQ} > 0$ and $C^i_{QQ}C^i_{BB} - (C^i_{QB})^2 > 0$, $i = 1, 2$.

The incumbent's choices of Q^1 and B determine its abatement, and the incumbent's first period profit (Π^1) is

$$(6) \quad \Pi^1(Q^1,B) = P(Q^1)Q^1 - C^1(Q^1,B) \quad .$$

The incumbent chooses Q^1 and B in period one to maximize profit *over both periods*. Whether or not its choice of B allows or deters entry in the second period is analyzed in the next section.

3.3 A Two-Stage Complete Information Game

The model is a two-stage game of complete information and is solvable by backward induction. The incumbent and potential entrant know the market demand function for generated electricity and both cost functions for its production. The critical element is that the incumbent can alter the outcome of the game to its advantage by banking permits in the first period for use in the second period. This choice affects its second period marginal cost of production and ultimately, the second period equilibrium outcome.

Government-imposed environmental regulation requires that polluting firms use an emissions allowance for each unit of emitted pollutant. As a result, the incumbent faces a binding environmental constraint. This constraint is trivially non-binding for the entrant because it emits no pollution. The regulator endows the incumbent firm with an exogenous number of permits at the beginning of each period. The incumbent may, however, bank some of these permits for use in the second period. By assumption, the incumbent only obtains allowances from the per period endowments. A market in tradeable pollution permits is not modeled. This omission simplifies the analysis significantly and does not detract from the qualitative conclusions. The implications for the inclusion of a permit market are discussed in a later section.

In period one, the incumbent monopolist chooses its first period output and the quantity of emissions allowances to bank for use in the second period. The incumbent's choice of permits to bank is unalterable once made. The potential entrant decides at the beginning of the second period whether or not to enter the market. If the potential entrant decides to enter, then it incurs a positive fixed cost, and the incumbent and entrant play a simultaneous game in which they compete in (second period) quantities. If the potential entrant decides not to enter, then the incumbent remains a monopolist in the second period.

If the incumbent banks sufficient permits in the first period, then it can produce a sufficient level of output to deter entry in the second period. Banking permits is costly to the incumbent in the first period and provides benefits *only* in the second period. If the incumbent chooses entry deterrence then it receives a lower level of profit in the first period relative to accommodation. This tradeoff between first and second period profit implies that the incumbent chooses the equilibrium strategy which yields the highest two-period profit.[16] As a result, deterrence and accommodation outcomes depend on specific, qualitative assumptions about the market demand function and both firms' cost functions.

3.3.1 Second Period Monopoly

In the second period, before Q^2 must be chosen, the incumbent knows whether or not the entrant has paid the fixed cost required for production. If the potential entrant has not paid the fixed cost, the incumbent remains a monopolist in the second period. The incumbent's second period problem is

$$(7)\quad \max_{Q^2} \quad P(Q^2)Q^2 - C^2(Q^2,B) \quad ,$$

in which the assumptions of the previous section characterize the demand and cost functions. The firm chooses Q^2 in the second period taking B as given and then solves its first period problem, knowing its equilibrium profit from the second stage. The incumbent's first period problem [*UM*] is

$$(8)\ [UM]\!:\max_{B}\ \Pi^M = P(Q^1(B))Q^1(B) - C^1(Q^1(B),B) + P(Q^*(B))Q^*(B) - C^2(Q^*(B),B)$$

where the incumbent's second period equilibrium profit as a monopolist is

$\Pi^*(B) = P(Q^*(B))Q^*(B) - C^2(Q^*(B), B)$[17].

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[16] For simplicity, a discount factor is not used. Its inclusion complicates the model unnecessarily.

[17] For convenience, [*UM*] refers to the incumbent's profit-maximizing behavior in the two-period problem for which it is an *unconstrained monopolist* in the second period; *i.e.*, there is no *possibility* of entry.

The first order necessary condition for [*UM*] is[18]

$$(9) \quad -\frac{\partial C^{1}(Q^{1}(B),B)}{\partial B} - \frac{\partial C^{2}(Q^{*}(B),B)}{\partial B} = 0 \quad .$$

Condition (*9*) states that the firm chooses B to equate its first period marginal cost of banking permits to the marginal benefit of their cost reduction when used in the second period. Alternatively, these two terms are *output effects* in that the size of output affects the firm's marginal valuation of permits. The symmetry of the problem implies that the firm's output is the same in each period and therefore, its marginal valuation of permits is equal (in absolute value) across periods.

Lemma 1: *An incumbent firm that remains a monopolist in the second period chooses* $B^{*} = 0$ *as the unique solution to* [*UM*], *and its two-period equilibrium profit is* $\Pi^{M}(B) = \Pi^{1}(0) + \overline{\Pi}(0)$.

Proof: For all proofs, see 3.6.

The incumbent banks no permits in equilibrium. With the assumptions of equivalent per period endowments and a zero discount rate, the incumbent is indifferent to the period in which it produces. This result provides a useful benchmark for comparison to the duopoly outcome presented below.

3.3.2 Second Period Duopoly Competition

The timing of the game is such that given entry, the entrant pays the positive fixed cost ($f > 0$) and then competes with the incumbent in a quantity-setting game. Suppose that the entrant has paid the fixed cost. Its variable cost of production is $c(q)$, with marginal cost $c_q(q) > 0$.[19] The entrant's revenue is $r(q + Q^2) = P(q + Q^2)q$, where the market price depends on the entrant's own output (q) as well as on the incumbent firm's output. The entrant's total and marginal revenue functions depend on the incumbent's output and *vice versa*:

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[18] Since the problem is symmetric, it can be solved with the incumbent choosing Q^1, Q^2, and B in the first period. Using the first order conditions with respect to Q^1 and Q^2, the cancellation of some terms gives (*9*).

$$(10) \quad r_Q < 0 \ , \ r_{qQ} < 0 \quad \textit{and} \quad R_q^2 < 0 \ , \ R_{Qq}^2 < 0 \quad .$$

After entry, the entrant's Cournot problem is

$$(11a) \quad \max_{q} \quad \pi = P(Q^2 + q)q - c(q) - f \ .$$

The incumbent must satisfy the second period environmental constraint, $E(Q^2, H^2) \leq L^2 + B$. Its second period cost function incorporates this constraint and any decisions related to abatement activities. The incumbent's second period Cournot problem is

$$(11b) \quad \max_{Q^2} \quad P(Q^2 + q)Q^2 - C^2(Q^2, B) \ .$$

For the second period Cournot game, each firm maximizes its profit with respect to its own output, given the output of the other firm and taking B as given. At this point, the incumbent already has chosen its level of B, and as a result, this choice determines both firms' equilibrium outputs and profits. The firms' Cournot reaction functions are

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[19] The superscript for the relevant period is omitted for the entrant since the second period is the only possibility for entry.

$$(12a)\quad \frac{\partial P(Q^2+q)}{\partial Q^2}Q^2 + P(Q^2+q) - \frac{\partial C^2(Q^2,B)}{\partial Q^2} = 0$$

$$(12b)\quad \frac{\partial P(Q^2+q)}{\partial q}q + P(Q^2+q) - \frac{dc(q)}{dq} = 0 \ .$$

Let $Q^2(q; B)$ and $q(Q^2; B)$ represent the incumbent's and entrant's reaction functions (respectively), in which the semicolon separates the choice variable from the parameter, *B*. *Lemma 2* characterizes these functions.

Lemma 2: *An increase in the incumbent's first period choice of banked permits (B) increases its own second period output (Q^2) and decreases the entrant's second period output (q).*

An increase in the incumbent's output decreases the entrant's level of output and market share because both depend on marginal cost. An increase in *B* by the incumbent decreases its own second period marginal cost. This cost reduction shifts the incumbent's reaction function outward and alters the equilibrium outcome. Solving the reaction functions simultaneously yields the firms' equilibrium outputs, $\bar{Q}(B)$ and $\bar{q}(B)$, which satisfy *(12a-12b)*. In addition, the incumbent's equilibrium profit ($\bar{\Pi}$) from the second period duopoly game is $\bar{\Pi}(B) = P(\bar{Q}(B) + \bar{q}(B))\bar{Q}(B) - C^2(\bar{Q}(B), B)$.

The incumbent's *unconstrained* two-period profit maximization problem [*UD*], in which it is a second period duopolist, is

$$(13)\,[UD]\!: \max_{B} \Pi^D = P(Q^1(B))Q^1(B) - C^1(Q^1(B),B) + P(\bar{Q}(B) + \bar{q}(B))\bar{Q}(B) - C^2(\bar{Q}(B),B)$$

Lemma 3: *For any choice of B, the incumbent's two-period profit when it is a monopolist in the second period is strictly greater than its profit when it is a duopolist in the second period; i.e.,* $\Pi^M(B) > \Pi^D(B), \forall B$.

Let $\bar{B}$ be the solution to [*UD*]. Using the firms' reaction functions (*12a-12b*), the necessary condition for [*UD*] is

$$(14) \quad -\frac{\partial C^1(Q^1(B),B)}{\partial B} - \frac{\partial C^2(\bar{Q}(B),B)}{\partial B} + \left[\frac{\partial P}{\partial \bar{q}}\frac{\partial \bar{q}}{\partial B}\bar{Q}(B)\right] = 0 \quad .$$

The first terms in (*9*) and (*14*) are identical; therefore, substitution of (*9*) into (*14*) yields

$$(15) \quad \frac{\partial \Pi^D}{\partial B}\Big|_{B=B^*} = \left[\frac{\partial C^2(Q^*(B^*),B^*)}{\partial B} - \frac{\partial C^2(\bar{Q}(B^*),B^*)}{\partial B}\right] + \left[\frac{\partial P}{\partial \bar{q}}\frac{\partial \bar{q}}{\partial B}\bar{Q}(B^*)\right] \quad .$$

Consider the [*UD*] problem and evaluate its associated first order condition (*14*) at the [*UM*] solution, $B^* = 0$. In a monopolist-duopolist comparison, typically $Q^* > \bar{Q}$ because the firm produces less output as a duopolist in the second period since its marginal revenue is lower. The result that $\partial^2\hat{C}^i/\partial Q^i\partial\Delta^i < 0$ implies that the first term in (*15*) is negative. The utility values an allowance more highly at the margin if it is producing a higher output. This marginal valuation is higher because it is relatively more costly for the utility to abate at the higher output with the same level of permit use.

The second term in (*15*) is positive because $\partial P/\partial\bar{q} < 0$ from the demand function, and $\partial q/\partial B < 0$ from *Lemma 2*. This term is the incumbent's increase in second period marginal revenue, applicable to its entire second period output, $\bar{Q}(B)$, that it obtains by reducing the entrant's equilibrium output through permit banking. This *competitive effect* is positive and opposes the output effect because it captures the incumbent's incentive to bank allowances in order to ensure effective duopoly competition in the second period.

If this effect dominates the output effect, then the sign of the first order condition is positive when evaluated at B^*. The implication is that the incumbent has the incentive to bank more allowances, relative to the case in which it operates as a monopolist, in order to gain market share in the second period. The sign, however, is ambiguous without more specific qualitative assumptions on both firms' cost functions. The incumbent's optimal choice of permits to bank in the [*UD*] case may be more or less than its optimal choice in the [*UM*] case. This result, in combination with the results of *Lemmas 1* and *3*, yields the representations in Figures *3-1* and *3-2*.

3.3.3 Accommodation and Deterrence

Before analyzing the incumbent's decision whether or not to allow entry, a determination of the critical level of banked permits that makes the potential entrant indifferent to entry is necessary. With a positive fixed cost of entry, this critical level of banked permits (B^C) satisfies

$$(16) \quad \pi_v^q(B^C) - f = 0 \quad ,$$

in which $\pi^q_v(B^C)$ is the potential entrant's variable profit as a function of the critical level.

The introduction of additional notation is useful. The requirement that no reverse banking occurs is now imposed on both the [*UM*] and [*UD*] problems. The proof of *Lemma 1* shows that $B^* = 0$; therefore, the inequality constraint is not binding for the

$[UM]$ case. In the subsequent analysis, B^* and B_M^* are used interchangeably. For the $[UD]$ case, the nonnegativity constraint binds only if $\bar{B} < 0$. The constrained solution is

$$(17) \quad \bar{B}_D = \underset{s.t.\ B \geq 0}{argmax}\ [UD] \quad .$$

In order to analyze the incumbent's possible actions toward the potential entrant, let $B' = \{B\colon \Pi^M(B) = \Pi^D(\bar{B}) \text{ and } B > 0\}$. B' is the larger value of B that equates monopoly profit with the incumbent's maximum duopoly profit.[20]

Figures *3-1* and *3-2* illustrate the entry deterrence and accommodation possibilities. In the figures, the incumbent's two-period profit ($\Pi^1 + \Pi^2$) is a function of B. The figure depicts both the $[UM]$ and $[UD]$ objectives and their respective maximizers, B^* and $\bar{B}$. From *Lemma 3*, the $[UM]$ objective lies everywhere above the $[UD]$ objective.

The incumbent's incentive is to choose the B which yields the highest two-period profit possible. If entry was not an issue, the incumbent would choose $B = B^*$ to obtain the two-period monopoly profit. There are three cases which apply to both figures: *i)* $B^C < B^*$, *ii)* $B^* < B^C < B'$, and *iii)* $B^* < B' < B^C$.

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[20] For the following analysis, it is necessary to use the larger root (B') that solves the equation: $\Pi^M(B) - \Pi^D(\bar{B}) = 0$.

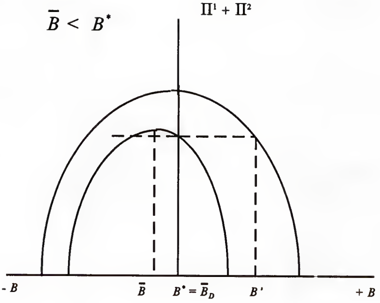

Figure 3-1: Strategic Banking

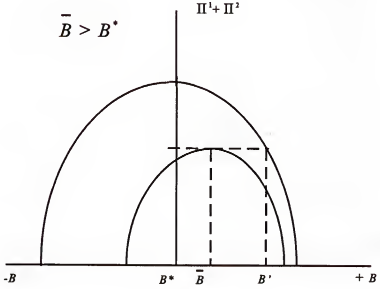

Figure 3-2: Non-strategic Banking

In either figure, for case *i*) the incumbent chooses B^* in equilibrium. A choice of B^C is sufficient to deter entry, but the incumbent increases its profit by banking permits up to the level, B^*. *Theorem 1a* presents this result.

Theorem 1a: *If* $B^C < B^*$, *the incumbent nonstrategically deters entry, and its subgame perfect Nash equilibrium choice of banked allowances is* B^*; *its two-period equilibrium profit is* $\Pi^1(B^*) + \Pi^*(B^*)$.

If $B^C < B^*$, then entry deterrence is nonstrategic because the incumbent banks more than the critical level of permits anyway because it wants to obtain the two-period monopoly profit. For case *ii*) $B^* < B^C < B'$, in either figure, the incumbent chooses B^C in equilibrium. *Theorem 1b* presents this result.

Theorem 1b: *If* $B^* < B^C < B'$, *then the incumbent strategically deters entry, and its subgame perfect Nash equilibrium choice of banked allowances is* B^C; *its two-period equilibrium profit is* $\Pi^1(B^C) + \Pi^*(B^C)$.

If the incumbent chooses B such that $B^C < B < B'$, then profit decreases since the incremental banked permits $(B - B^C)$ are excessive with respect to entry deterrence and simply increase the incumbent's costs. If the incumbent chooses B such that $B < B^C < B'$, then it does not deter entry, and profit decreases because entry leads to duopoly competition. The incumbent, therefore, has the incentive to bank exactly the critical level of permits necessary to deter entry - it strategically deters entry.

For case *iii*) $B^* < B' < B^C$, there are two subcases: *a*) $\bar{B} < 0$, and *b*) $\bar{B} > 0$. In *iiia*), the inequality constraint binds (Figure *3-1*), and the incumbent chooses $\bar{B}_D$ in equilibrium. In *iiib*), the inequality constraint does not bind (Figure *3-2*), and the incumbent chooses $\bar{B}$ in equilibrium.

Theorem 1c: *If $B^* < B' < B^C$, then the incumbent accommodates entry, and its subgame perfect Nash equilibrium choice of banked allowances is: a) $\bar{B}_D$ if $\bar{B} < 0$ with two-period equilibrium profit of $\Pi^1(\bar{B}_D) + \bar{\Pi}(\bar{B}_D)$, or b) $\bar{B} > 0$ if $\bar{B} > 0$ with two-period equilibrium profit of $\Pi^1(\bar{B}) + \bar{\Pi}(\bar{B})$.*

In either subcase, the incumbent obtains the highest profit possible by accommodating entry. If the incumbent chooses B, such that $B > B'$, then profit is less than the profit attainable at the duopoly optimum. Specifically, if $B' < B < B^C$, the incumbent does not deter entry. Its optimal choice of B is the duopoly equilibrium choice, $\bar{B}$ ($\bar{B}_D$ if $\bar{B} < 0$). Alternatively, if $B' < B^C < B$, its optimal choice remains $\bar{B}$ ($\bar{B}_D$ if $\bar{B} < 0$) because the incremental banked permits are only costly and provide no additional benefit.

In subcase *a*), accommodation occurs with no banking by the incumbent due to the binding constraint. As a result, Figure *3-1* implies that any banking ($B > 0$) is strategic in motivation. Alternatively, Figure *3-2* implies that banking may or may not be strategic because for subcase *b*), the fact that the constraint is non-binding implies $\bar{B} > 0$ is an equilibrium choice if $B' < B^C$. Table *3-1* summarizes these cases:

Table *3-1*: Accommodation and Deterrence Possibilities

Case	Condition	Equilibrium choice	Implication
i.	$B^C < B^*$	B^*	nonstrategic deterrence
ii.	$B^* < B^C < B'$	B^C	strategic deterrence
iiia.	$B^* < B' < B^C$ and $\bar{B} < 0$	$\bar{B}_D = B^*$	accommodation w/ no banking
iiib.	$B^* < B' < B^C$ *and* $\bar{B} > 0$	$\bar{B}$	accommodation w/ banking

3.4 An Emissions Permit Market

The incorporation of a permit market into the previous analysis introduces some interesting issues. Suppose a market operates in the first period and also in the second period. A basis for trade in the market requires at least two types of firms, one with high abatement costs and one with low abatement costs. This requirement simply implies that two regional monopolies are necessary, one with each type of abatement cost.

A crucial issue is the relationship between the permit price in each period. Let p_1 denote the permit price in period one and p_2 denote the price in period two. If $p_1 < p_2$, then this situation is not an equilibrium because firms will arbitrage away the price differential. They buy permits in period one and sell them in period two. Arbitrage occurs until prices are equal across periods. If $p_1 = p_2$ initially, then no distinction exists between permits. They are perfectly substitutable, and as a result, the quantity of permits banked is indeterminate.

The final possibility is that $p_1 > p_2$. In this case, the problem is that no incentive exists for banking in the first period because permits are cheaper in the second period. If the timing structure allows incumbents in the second period to buy and sell permits prior to entry, then they will not bank permits in the first period because banking costs relatively more. If the timing structure enables incumbents to buy and sell permits only after entry occurs, then banking permits is not a credible threat of deterrence. The potential entrant enters anyway and forces the incumbent to reoptimize. Permit banking in the first period is not a credible commitment, and any outcome with banking is not subgame perfect. It is not rational for an incumbent to bank permits on an individual basis.

Collusion among incumbents makes banking credible. If incumbent firms collude and agree not to sell any banked permits in the second period, then banking becomes credible. This strategy requires the incumbents to monitor each other or to enforce the agreement such that no firm sells permits in the second period. This collusive activity makes banking credible because it effectively eliminates the second period permit market.

3.5 Conclusion

This chapter provides one explanation for the stylized fact that large, coal-fired generators are over-controlling their emissions and banking surplus permits. The potential for entry into regional electricity markets by clean independent power producers may affect these incumbents' incentives for current permit use and therefore permit banking. Permit banking essentially represents a current period investment in future cost reduction. Banking decreases firms' future costs of production because the availability of banked permits enables firms to decrease costly (future) abatement activities.

This chapter demonstrates three possible outcomes from banking. One possibility is that the incumbent utility nonstrategically deters entry. The firm's choice of banked permits that maximizes its two-period profit exceeds the critical level of permits necessary to deter entry. The second possibility is that the incumbent strategically deters entry. In this case, its equilibrium choice of permits exactly equals the critical quantity. If the incumbent banks more than this level, the excess banking lowers its two-period profit because it raises first period costs without producing additional second period benefits. If the incumbent banks less than this level, then its profit decreases significantly because it no longer deters entry. The third possibility is that the incumbent accommodates entry. In this case, its two-period profit optimization induces it to choose a quantity of permits that supports the post-entry duopoly equilibrium outcome. The critical level of permits for entry deterrence is too high in the sense that banking the critical level increases first period costs prohibitively.

In any of these three cases, permit banking reduces the incumbent firm's future costs of production. The specific form of the incumbent's and potential entrant's demand and cost functions, including the magnitude of the fixed cost necessary for entry, determine the critical level of permits and the conditions under which the incumbent firm accommodates or deters entry. An obvious extension of this work is a simulation that uses the structure and assumptions of this model. Such a simulation would determine the demand and cost conditions that characterize the accommodation and deterrence cases.

3.6 Proofs

Proof of Lemma 1

Since the incumbent's single period problems are symmetric, its first period problem (*8*) collapses to:

$$(A1)\quad [UM]:\quad \max_{Q^1 Q^2, B} \quad \Pi^M = P(Q^1)Q^1 - C^1(Q^1,B) + P(Q^2)Q^2 - C^2(Q^2,B) \ .$$

For strict concavity of the profit function, $\Pi^M(Q^1, Q^2, B)$, the principal minors of its Hessian determinant ($|H|$) must alternate in sign, starting with negative. The Hessian is

$$\begin{bmatrix} \Pi_{Q^1Q^1} & \Pi_{Q^1Q^2} & \Pi_{Q^1B} \\ \Pi_{Q^2Q^1} & \Pi_{Q^2Q^2} & \Pi_{Q^2B} \\ \Pi_{BQ^1} & \Pi_{BQ^2} & \Pi_{BB} \end{bmatrix} .$$

Let H_{ij} denote the entry of the ith row and jth column. The condition for strict concavity first requires that sign $|H_{11}| < 0$. $|H_{11}| = R^1_{QQ} - C^1_{QQ} < 0$. Second, $(\Pi_{Q^1Q^1})(\Pi_{Q^2Q^2}) - (\Pi_{Q^2Q^1})^2 > 0$. Since $\Pi_{Q^2Q^1} = \Pi_{Q^1Q^2} = 0$, this condition is $(R^1_{QQ} - C^1_{QQ})(R^2_{QQ} - C^2_{QQ}) > 0$. Finally, strict concavity also requires that $|H| < 0$. Expanding by the first column gives the expression:

$$(A2)\ \det(H) = C^1_{BB}(R^1_{QQ} - C^1_{QQ})\left\{ - R^2_{QQ} + C^2_{QQ}\left[- R^2_{QQ}C^2_{BB} + C^2_{QQ}C^2_{BB} - \left(C^2_{QB}\right)^2\right]\right\} .$$

Strict convexity of the cost function implies $C^2_{QQ}\, C^2_{BB} - (C^2_{QB})^2 > 0$. The expression in [·] in (*A2*) therefore is positive since $R^2_{QQ} < 0$ and $C^2_{BB} > 0$. It follows that the expression in {·} is also positive and that $|H|$ is negative. The first order conditions for [*UM*] are

$$\begin{aligned} (A3)\quad \frac{\partial \Pi}{\partial Q^1} &= P_Q(Q^1)Q^1 + P(Q^1) - C^1_Q(Q^1, B) \le 0 \\ \frac{\partial \Pi}{\partial Q^2} &= P_Q(Q^2)Q^2 + P(Q^2) - C^2_Q(Q^2, B) \le 0 \\ \frac{\partial \Pi}{\partial B} &= - C^1_B(Q^1, B) - C^2_B(Q^2, B) \le 0 \end{aligned}$$

Let B^* be the solution that satisfies the three first order conditions above. If $B^* = 0$, then $Q^1 = Q^2 = Q^*$ solves $P_Q(Q^*)Q^* + P(Q^*) - C_Q(Q^*, 0) = 0$ for the first two conditions in (*A3*). Since the profit function is strictly concave, $B^* = 0$ is the unique solution as well.▪

Proof of Lemma 2

(*i*) The implicit reaction functions of the entrant and the incumbent from the second period Cournot game (respectively) are

$$(A4)\quad \pi_q^{\,q} = r_q(Q,q) - c_q = 0$$
$$(A5)\quad \Pi_Q^{\,Q} = R_Q(Q,q) - C_Q(Q,B)$$

Total differentiation of these implicit reaction functions, (*A4*) and (*A5*), respectively yields

$$(A6)\quad d\pi_q = r_{qQ}dQ + r_{qq}dq - c_{qq}dq = 0$$
$$(A7)\quad d\Pi_Q = R_{QQ}dQ + R_{Qq}dq - C_{QQ}dQ - C_{QB}dB = 0 \quad ,$$

where the superscripts indicating the incumbent's second period output are omitted for clarity. From (*A6*) the slope of the entrant's reaction function is $dq/dQ = - r_{qQ} / (r_{qq} - c_{qq}) < 0$, since $(r_{qq} - c_{qq}) < 0$ by assumption and $r_{qQ} < 0$. Similarly, from (*A7*), $dQ/dq = - R_{Qq} / (R_{QQ} - C_{QQ}) < 0$.

(*ii*) The system in (*A6*, *A7*) can be written as

$$\begin{bmatrix} R_{QQ} - C_{QQ} & R_{Qq} \\ r_{qQ} & r_{qq} - c_{qq} \end{bmatrix} \begin{bmatrix} \dfrac{dQ}{dB} \\ \dfrac{dq}{dB} \end{bmatrix} = \begin{bmatrix} C_{QB} \\ 0 \end{bmatrix} .$$

Let H represent the determinant of the 2x2 matrix. Comparative statics analysis yields:

$$(A8) \quad \frac{\partial Q}{\partial B} = \frac{C_{QB}(R_{QQ} - C_{QQ})}{H} \quad , \quad \frac{\partial q}{\partial B} = \frac{-C_{QB} r_{qQ}}{H} \quad .$$

$\partial Q/\partial B > 0$ since $C_{QB} < 0$, $(R_{QQ} - C_{QQ}) < 0$, and $H > 0$ by assumption. $\partial q/\partial B < 0$ since $C_{QB} < 0$, $r_{qQ} < 0$, and $H > 0$.▪

Proof of Lemma 3

First, fix the level of B. The first period profit functions in both the [*UM*] and [*UD*] problems are identical and therefore can be ignored. The incumbent as a second period monopolist maximizes $\Pi^M(Q) = P(Q)Q - C(Q)$, while the incumbent as a second period duopolist maximizes $\Pi^D(Q) = P(Q+q)Q - C(Q)$. Subtracting yields: $\Pi^M(Q) - \Pi^D(Q) = [P(Q) - P(Q+q)]Q > 0$; therefore, $\Pi^M(Q) > \Pi^D(Q, q)$, any Q and $q > 0$. Let Q^D maximize $\Pi^D(Q)$ and Q^M maximize $\Pi^M(Q)$. It follows that $\Pi^M(Q^D) > \Pi^D(Q^D+q)$. Since $\Pi^M(Q^M)$ is the maximized value, then $\Pi^M(Q^M) \geq \Pi^M(Q^D)$. By transitivity, $\Pi^M(Q^M) > \Pi^D(Q^D+q)$, any B .▪

Proof of Theorem 1a

As given in *Theorem 1a*, suppose $B^C < B^*$. If $B < B^C$, then entry occurs, and the incumbent's profit is $\Pi^1(B) + \bar{\Pi}(B) < \Pi^1(B^*) + \Pi^*(B^*)$ since B^* is the maximizer.

At B^C, the incumbent receives profit $\Pi^1(B^C) + \Pi^*(B^C)$. The incumbent, however, increases profit by increasing B to B^*, since B^* is the maximizer. A choice of B^* deters entry as well; therefore, the incumbent can attain a profit no higher than the profit obtainable at B^*, the maximizer of [*UM*]. ▪

Proof of Theorem 1b

As given in *Theorem 1b*, suppose $B^* < B^C < B'$. If $B^C < B < B'$, then $\Pi^1(B) + \Pi^*(B) < \Pi^1(B^C) + \Pi^*(B^C)$ since $\Pi^1(B) + \Pi^2(B)$ is concave, and the maximizer, B^*, is such that $B^* < B^C < B$. Alternatively, if $B < B^C < B'$, then entry occurs. With entry, the incumbent's profit is $\Pi^1(\bar{B}) + \bar{\Pi}(\bar{B}) < \Pi^1(B^C) + \Pi^*(B^C)$. As a result, the incumbent chooses $B = B^C$.▪

Proof of Theorem 1c

As given in *Theorem 1c*, suppose $B^* < B' < B^C$. Consider Figure *3-1*, which applies to case *i*). If $\bar{B} < 0$, then $\bar{B}_D = 0$. If $B' < B < B^C$, and the incumbent does not deter entry, then $\Pi^1(B) + \bar{\Pi}(B) < \Pi^1(\bar{B}_D) + \bar{\Pi}(\bar{B}_D)$ since $\bar{B}_D$ is the maximizer. If $B' < B^C < B$, then $\Pi^1(B) + \Pi^*(B) < \Pi^1(\bar{B}_D) + \bar{\Pi}(\bar{B}_D)$; therefore, it is suboptimal for the incumbent to deter entry. As a result, the incumbent chooses $\bar{B}_D = 0$ and accommodates entry. Consider Figure *3-2*, which applies to case *ii*). If $\bar{B} > 0$, then $\bar{B}_D = \bar{B}$. The proof for case *ii*) is the same as the proof for case *i*).▪

CHAPTER 4
THE USE OF TRADEABLE POLLUTION PERMITS TO ACHIEVE ECONOMIC EFFICIENCY IN THE PRESENCE OF PRODUCTION EXTERNALITIES AND DECENTRALIZED BARGAINING

4.1 Introduction

Two distinct approaches address the negative externality problems associated with the emission of pollution as a by-product of production. The first approach, associated with Pigou (1920), proposes governmental use of corrective taxation. The implementation of the socially optimal tax compels polluting firms to internalize fully the social cost of their emissions. As a result, corrective taxation sustains a socially efficient allocation. The second approach, attributable to Coase (1960), involves decentralized bargaining among parties over an agreeable level of the externality. Coase demonstrated that with zero bargaining costs, this process yields an efficient outcome regardless of the initial assignment of property rights - whether the polluter possesses the right to impose damage on others, or the damaged party possesses the right to prevent pollution. These two approaches imply that Pigouvian taxation is the preferable instrument for obtaining efficiency when decentralized bargaining is costly.

The literature on Pigouvian taxation raises two important issues with respect to requirements for supporting a Pareto optimal allocation. The first issue is the use of taxes not only to attain the optimal level of pollution but to ensure the efficient number of firms under the long run condition of free entry. Baumol (1972), Schulze and d'Arge (1974), Baumol and Oates (1988), and Carlton and Loury (1980) showed that in the long run, a linear tax on the externality can sustain an efficient allocation, provided consumers receive the tax revenue as lump-sum income.

The second issue addresses the use of Pigouvian taxes in the short run when decentralized bargaining among firms is possible. Although taxation and bargaining each independently lead to the optimal allocation, Buchanan and Stubblebine (1962) and Turvey (1963) demonstrated that the use of corrective taxation when bargaining is possible yields an inefficient allocation if consumers receive tax revenue as lump-sum payments. Firms bargain to alter the output of the damaging commodity in order to reduce the revenue outflow. Both industries obtain higher profit after making appropriate bribes. Alternatively, if the regulator transfers the tax revenue to the damaged industry, the outcome is efficient in the short run.

The implication of these two results is that inducing the efficient number of firms and preventing inefficiencies when bargaining interacts with taxation depend upon how the government spends the tax revenue. The problem is that satisfying both simultaneously appears impossible because the requirements for each are inconsistent. Hamilton *et al.* (1989) reconciled these requirements by showing that the use of a nonlinear tax system sustains the optimal allocation under conditions of free entry into both the damaging and the damaged industries even if bargaining is costless. In their nonlinear tax system, the regulator chooses a tax rate on damaging firms' output above the optimum quantity.[1] It also charges a franchise tax on entry into the damaging industry equal to the uncharged tax on output below the socially optimal level and transfers the revenue to consumers as lump-sum payments. This scheme supports the socially optimal allocation because it eliminates firms' opportunities to increase their profits through strategic bargaining. The Pigouvian tax does not raise any net revenues. Firms do not perceive any revenue outflow and cannot benefit by adjusting the level of the damaging activity. The franchise tax extracts the damaging firms' extra revenue and therefore prevents entry beyond the first-best number of firms.

For environmental economists, the use of tradeable pollution permits (TPPs) as an alternative to corrective taxation is a popular solution to negative externality problems.[2] The principal economic explanation for externalities is the absence of a complete set of private property rights. The use of tradeable permits fills this void by providing the appropriate "missing market." [3] A permit is a property right to emit one unit of a given pollutant in the current year.[4] In general, a regulator decides the aggregate quantity of pollution allowable in a compliance year. It then allocates or sells through an auction a quantity of permits such that the total quantity of emissions equals the cap.[5] Environmental compliance requires that polluting firms hold a number of permits equal to the tons of emitted pollutant in a given compliance period.

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[1] This determination assumes that supply originates from firms maximizing profit separately.

[2] Throughout the chapter, the terms "permit" and "allowance" are used interchangeably.

[3] Dales (1968) originally advocated the use of tradeable pollution permits.

[4] Under Title IV of the Clean Air Act Amendments (1990) participants in the market for sulfur dioxide emissions rights have the option to bank permits for use in a future year.

The efficiency properties of such a system in comparison to corrective taxes is analyzed in the literature, but the possibility of bargaining among firms is not considered. In the absence of bargaining, the use of an emissions permit system functions as well as a tax to support an efficient allocation in the short and long runs. In both cases, the requirement that polluting firms purchase a property right to pollute at a price equal to marginal social damage ensures that they fully internalize the external cost of their emissions. With free entry, support of the efficient allocation also requires that the government distributes permit revenue to consumers as lump-sum payments. If the government instead distributes these revenues to firms in the damaged industry, then excess entry occurs into the latter.

This paper determines the conditions under which the use of an emissions permit system, as an alternative to corrective taxation, sustains the efficient allocation if bargaining among firms is possible. With a fixed number of firms and bargaining, a conventional permit system in which firms purchase permits in individual units sustains the first-best allocation. Coasian bargaining implies that firms in the damaging industry evaluate the effects of their damage on joint industry profit. They negotiate with the firms in the damaged industry, and bargaining induces the industries to produce the socially optimal quantity of each output. Firms in the damaging industry, therefore, will not purchase permits if the price is positive. Unlike the case with no bargaining, a permit market price equal to marginal social cost is no longer market-clearing. Firms in the damaging industry will economize on their permit use and will bid the permit price to zero. Essentially, the regulator must give away permits to polluting firms. Decentralized bargaining makes the permit system completely redundant.

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[5] In an emissions permit system (EPS), the regulator denominates permits in units of pollutant emitted; that is, one permit gives the owner the right to emit one ton of pollutant into the atmosphere. The EPS implies that trades between firms are at a one-to-one rate.

A conventional permit system with free entry and bargaining is alone insufficient to sustain the first-best allocation. Bargaining among firms ensures that firms want to economize on their use of permits. As a result, the market clears only with an equilibrium permit price equal to zero. This price induces excess entry into the damaging industry, and the socially efficient outcome is not sustainable.

A *block permit system* is sufficient to sustain the first-best allocation in the presence of bargaining and free entry. Polluting firms must purchase permits in blocks from the regulator, and the requirement for entry into the damaging industry is a minimum purchase of a single block.[6] Each block allows exactly the socially optimal level of pollution per firm. The regulator charges a block price equal to the product of marginal damage and per firm emissions, both evaluated at the social optimum. The purchase requirement for entry prevents incumbent firms from reducing their output and selling unused permits to an entrant. The block permit system sustains the first-best allocation because block sales mimic the function of a franchise tax on entry.

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[6] In other words, only “block buyers” can purchase permits.

4.2 A Competitive Economy With an Emissions Permit System

Two industries, *X* and *Y*, comprise a competitive economy. There are n_x identical firms in industry *X*, and each produces a single good, *x*. Similarly, there are n_y identical firms in industry *Y*, and each produces a single good, *y*. Output per firm in industry *X* is $x = X/n_x$, and output per firm in industry *Y* is $y = Y/n_y$. Labor is the only variable input used for the production of goods *x* and *y*.

A representative firm in industry *X* produces good *x*, and its strictly convex labor requirement function is $F(x)$. Its technology is such that atmospheric pollution is a by-product of its output. This pollution is a negative externality and damages firms in industry *Y* by increasing their production costs. Firms in industry *Y* do not generate pollution. In the traditional Pigouvian approach to negative externalities, an efficient allocation is attainable with a tax equal to marginal social damage, with the revenue distributed to consumers as lump-sum income. This solution yields both the level of production and the number of firms in the industry that sustain the first-best allocation.

An individual firm in industry *X* has a net emissions function, $e(x, b)$, which depends on output per firm and abatement input (b). Aggregate abatement for industry *X* is $B = n_x b$. A firm may abate emissions at the constant cost, δ. For a given level of abatement, the marginal effect of output on emissions is positive: $e_1 \equiv \partial e/\partial x > 0$, and for a given level of output, the marginal effect of abatement on emissions is negative:

$e_2 \equiv \partial e/\partial b < 0$.[7] In addition, $e(x, b)$ is convex in x and b. The atmospheric quality of the externality implies that only total emissions, $E = n_x e(x, b)$, are relevant; their distribution across firms is irrelevant. The labor requirement function of a firm in industry Y is $G(y, n_x e(x, b))$ in which G is increasing in both y and E, and G is strictly convex in y and E jointly.

The government regulator utilizes an emissions permit system to address the negative externality problem.[8] By assumption, the regulator does not utilize corrective taxation. The regulator observes pollution damage directly as well as the market-clearing allowance price.

At the beginning of a given period, the government sets the emissions cap equal to the socially optimal level of pollution, $n_x^* e^*$ and then makes available the equivalent supply of allowances, $\overline{A} = n_x^* e^*$. A polluting firm must hold an allowance for each unit of pollutant it emits during a given time period (typically a year) to attain environmental compliance. A firm can relax its environmental constraint by reducing output, abating emissions, and/or acquiring additional permits. An emission requires the consumption of one allowance, and a firm must acquire additional allowances for emissions in future periods.[9]

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[7] Numerical subscripts indicate partial derivatives.

[8] The terms government and regulator are used interchangeably throughout the chapter; they refer to the same entity.

[9] In this model, firms cannot borrow or bank allowances. Intertemporal allocation of allowances further complicates the analysis and is not crucial to the purpose of this paper.

The emissions allowance market is competitive, and the market price of a permit is γ. Firms believe that they cannot individually affect the allowance price. Specifically, an individual firm in industry *X* demands a_x allowances. The environmental constraint requires that an individual firm satisfies $e(x, b) \leq a_x$. By assumption, firms in industry *X* use any allowances that they purchase for compliance purposes. [10] Since firms will not hold more allowances than necessary for compliance, the emissions constraint binds: $e(x, b) = a_x$. Industry *X* demands exactly $n_x e$ allowances because it must hold an allowance for each unit of pollutant emitted into the atmosphere.

Firms in industry *Y* also have the option to purchase allowances.[11] Although these firms do not pollute, their collective purchase of allowances increases the market price of permits and reduces the quantity demanded by industry *X*. The resulting decrease in emissions by industry *X* decreases the costs imposed on firms in industry *Y*. The problem, however, is that a free-rider incentive exists with respect to the individual permit demand by firms in industry *Y*. It is shown later that industry *Y* demands zero allowances because of this free-rider problem. Given firms' demands for allowances and the fixed supply, the market determines the price such that quantity demanded equals quantity supplied. It follows that each firm's profit-maximizing choice of output is attainable.

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[10] Although it is possible that firms may have an incentive to acquire extra allowances for entry deterrence purposes, this strategic possibility detracts from the main focus.

[11] In general, any individual or entity may participate in emissions permit markets.

Before analyzing the operation of an emissions permit system in a competitive economy, it is useful to characterize the first-best allocation for the economy. The economy consists of m identical individuals who have the same quasi-linear utility function, $\hat{u}(X/m, Y/m, L/m)$, which is separable in the numeraire good, labor; that is, $\hat{u}(X, Y, L) = \tilde{u}(X/m, Y/m) - (L/m)$.[12] The social welfare function for the economy is

$$(1)\quad W = m\tilde{u}(X/m, Y/m) - L = u(X,Y) - n_x F(X/n_x) - n_y G(Y/n_y, n_x e(X/n_x, B/n_x)) - \delta B \ .$$

By assumption, $u(X, Y)$ is strictly concave in X and Y. The social planner chooses X, Y, B, n_x, and n_y to maximize W. The first order necessary conditions for the social optimum are

$$(2a)\quad \frac{\partial W}{\partial X} = u_1 - F' - n_y G_2 e_1 = 0$$

$$(2b)\quad \frac{\partial W}{\partial Y} = u_2 - G_1 = 0$$

$$(2c)\quad \frac{\partial W}{\partial B} = (-n_y G_2 e_2) - \delta = 0$$

$$(2d)\quad \frac{\partial W}{\partial n_x} = xF' - F + n_y G_2(e_1 x + e_2 b - e) = 0$$

$$(2e)\quad \frac{\partial W}{\partial n_y} = yG_1 - G = 0$$

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[12] This form avoids the complication of income effects altering the first-best allocation. Quasi-linear utility ensures that there is a unique efficient allocation which is independent of taxes or property rights. It also makes possible aggregation to a single representative consumer.

These conditions implicitly define the first-best allocation for the economy.[13] Given the concavity and convexity assumptions on the functions u, G, and F, the first order conditions are sufficient.[14] Condition (*2a*) states that at the social optimum a representative consumer's marginal utility from good X is equal to the sum of its marginal cost of production and the marginal damage from the externality. Condition (*2b*) states that the marginal utility from good Y is equal to its marginal cost of production. From condition (*2c*), the term, $(-\,n_y G_2\, e_2)$, is the marginal benefit from abatement in reducing pollution damage. Conditions (*2d-2e*) ensure the efficient scale for each industry. Condition (*2e*) states that the marginal production cost for good Y is equal to its average cost. Finally, (*2d*) implies that the marginal social cost of good X equals its average cost.

In this section, the use of an emissions permit system to sustain the socially optimal allocation given free entry into each industry is demonstrated.[15] Consider first a competitive economy that operates without taxes. Instead, a regulator uses an emissions permit system to address the externality issue. Firms may freely enter and exit either industry X or industry Y, but firms cannot bargain with each other. The price vector for this economy is $p = (p_x, p_y)$ for goods x and y. Labor is the numeraire commodity.

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[13] Arguments of functions are suppressed when obvious.

[14] In addition to the convexity of the functions, G and e, several conditions, such as e being close to constant returns to scale, are required for W to be concave in all choice variables.

[15] With a fixed number of firms, the analysis yields qualitatively identical results; therefore, the short run case is omitted.

An individual firm in industry X chooses x and b to maximize its profit, $\pi_x = p_x x - F - \gamma e - \delta b - \kappa_x$, where κ_x is a franchise fee for entry into industry X. The binding environmental constraint implies that the firm's demand for permits is $a_x = e$. Its first order conditions for profit maximization are

$$(3a)\quad \frac{\partial \pi_x}{\partial x} = p_x - F' - \gamma e_1 = 0 \qquad (x>0)$$

$$(3b)\quad \frac{\partial \pi_x}{\partial b} = -\delta - \gamma e_2 = 0 \qquad (b>0).$$

In addition, the assumptions of identical firms and free entry impose the zero profit condition for an individual firm:

$$(3c)\quad p_x x - F - \gamma e - \delta b - \kappa_x = 0 \quad .$$

Similarly, a firm in industry Y chooses y and a_y to maximize its profit: $\pi_y = p_y y - G(y,\ \bar{A} - (n_y - 1)\bar{a}_y - a_y) - \gamma a_y - \kappa_y$, where κ_y is a franchise fee for entry into industry Y net any compensation to damaged firms in this industry, and a_y is the demand for allowances by a firm in industry Y. The second argument of G is total pollution, $n_x e$. The average demand for allowances by a firm in industry Y is $\bar{a}_y$; therefore, the industry demand is $(n_y - 1)\bar{a}_y + a_y$. The first order conditions for profit maximization are

$$(4a)\quad \frac{\partial \pi_y}{\partial y} = p_y - G_1 = 0\ ; \qquad (y>0)$$

$$(4b)\quad \frac{\partial \pi_y}{\partial a_y} = G_2 - \gamma \le 0\ ; \qquad a_y\left(\frac{\partial \pi_y}{\partial a_y}\right) = 0$$

From *(4b)*, $\partial\pi_y/\partial a_y < 0$ if $\gamma > G_2$ implying that $a_y(p_y,\gamma,\delta) = 0$. Therefore, a range of allowance prices exists such that $a_y = 0$. With free entry, a firm in industry Y makes zero profit in the long run:

$$(4c) \quad p_y y - G - \kappa_y = 0 \quad .$$

A representative consumer maximizes utility subject to income, with consumer income (I) defined as the sum of wage income (L), allowance revenue received (R^a), and firm profits (Π). In decision-making, the consumer takes Π and R^a as given. The consumer's problem is to choose x and y to maximize $u(X, Y) - L$, subject to $q_x X + q_y Y \leq L + \Pi + R^a$. The first order conditions are

$$\begin{aligned} &(5a) \quad u_1 = q_x \\ &(5b) \quad u_2 = q_y \quad . \end{aligned}$$

A vector $(p_x^*, p_y^*, \gamma^*, n_x^*, n_y^*, x^*, y^*, b^*, \kappa_x^*, \kappa_y^*, L^*)$ is consistent with a competitive equilibrium if equations *(3-5)* and equations *(6-7)* below are satisfied:

$$\begin{aligned} &(6) \quad L^* \geq n_x^* F(x^*) + n_y^* G(y^*,\ n_x^* e(x^*, b^*) \\ &(7) \quad n_x^* e(p_x^*, p_y^*, n_x^*, n_y^*, \gamma^*) = \overline{A} \quad . \end{aligned}$$

Equations *(3-4)* and *(5a-5b)* imply respectively that firms in each industry are maximizing profits and consumers are maximizing utility. Equation *(6)* is the condition for market-clearing in the labor market. Equation *(7)* guarantees that the allowance market clears.

Theorem 1: *Let* $(\overline{X}, \overline{Y}, \overline{B}, \overline{n}_x, \overline{n}_y)$ *define the first-best allocation for an economy with no corrective taxation and with free entry into each industry. With an emissions permit system and no bargaining among firms,* $\gamma^* = \overline{n}_y G_2(\overline{Y}/\overline{n}_y, e(\overline{X}/\overline{n}_x, \overline{B}/\overline{n}_x))$, $p_x^* = F'(\overline{X}/\overline{n}_x) + \gamma^* e_1(\overline{X}/\overline{n}_x, \overline{B}/\overline{n}_x)$, $p_x^* = G_1(\overline{Y}/\overline{n}_y, e(\overline{X}/\overline{n}_x, \overline{B}/\overline{n}_x))$, $\kappa_x^* = \kappa_y^* = 0$, *and* $R^a = \gamma^* e_2(\overline{X}/\overline{n}_x, \overline{B}/\overline{n}_x)$ *yields a market equilibrium that sustains the first-best allocation.*

Proof: For all proofs, see 4.4.

The conventional permit system is an effective substitute for Pigouvian taxation. The regulator chooses the quantity of permits available to firms instead of a corrective tax on output. With free entry into both industries possible, firms pay the cost of pollution when purchasing permits. A firm in industry *X* produces the first-best output and demands the first-best quantity of permits. The regulator transfers the permit revenue to consumers as lump-sum income. If the regulator instead transfers the revenue to firms in industry *Y* as compensation, the first-best allocation is not sustainable because the externality is double-counted. As a result, the transfer induces excess entry into industry *Y*.

4.2.1 Bargaining and a Fixed Number of Firms

The previous section demonstrates the well-known result that an emissions permit system can sustain the efficient outcome. Bargaining among firms upsets this result under certain conditions. The use of an emissions permit system with bargaining and a fixed number of firms is analyzed.

A crucial assumption of the analysis involves the informational asymmetry between the regulator and the industries. By assumption, the government cannot observe whether or not bargaining occurs among firms. The regulator does not know if firms will determine their output and emissions choices by independent maximization or by bargaining. Although the regulator observes pollution damage, it can only deduce *ex post* whether or not bargaining has occurred. The problem is that its decision to implement an emissions permit system occurs *ex ante.* If bargaining does not occur, then the permit system is necessary to induce firms to internalize the externality. If bargaining does occur, the permit system is unnecessary, but the regulator does not know this fact *ex ante.*

The Coasian approach to short run bargaining does not specify a formal structure. It assumes that negotiation among a fixed number of firms incurs no transaction costs, and parties appropriate all gains from the bargaining process. Decentralized bargaining involves negotiating the division of gains from joint profit maximization by the two industries. One assumption made about this process is that firms do not utilize negotiations to cartelize industry output. Firms then take producer prices as given when maximizing joint profit. Without any taxation, the bargaining outcome is the solution to the program:

$$(8) \quad \max_{\{x,y,b\}} \quad \bar{\pi} \equiv p_x n_x x + p_y n_y y - n_x F(x) - n_y G(y, n_x e(x,b)) - \gamma n_x e(x,b) - \delta n_x b$$

where $\bar{\pi}$ is joint profit between the industries.

An important issue in bargaining is the distribution of profit among the firms. Distribution depends on both the legal rules and the structure of the bargaining process. This structure either: *i*) determines if there is a liability rule, or *ii*) assigns complete property rights to *a*) industry *X*, *b*) industry *Y*, or *c*) a third party. Regardless of the prevalent structure, a rule exists for the division of joint profit. As a result, any party can purchase property rights from the regulator.

Industry profits attainable through independent profit maximization are π_x and π_y. Joint profit is $\bar{\pi}$. In addition, $s^x(\bar{\pi}, \pi_x, \pi_y)$ and $s^y(\bar{\pi}, \pi_x, \pi_y)$ represent the respective surplus for each industry as the result of bargaining. If industry *X* possesses complete property rights, then $s^y = \pi_y$ and $s^x = \bar{\pi} - \pi_y$ is the division; industry *X* extracts all surplus above the independent maximization outcome for industry *Y*. If industry *Y* possesses the property rights, then the division is $s^x = 0$ and $s^y = \bar{\pi}$. Industry *Y* shuts down industry *X* and extracts all surplus. In this last case, the outcome for industry *X* is worse than its outcome from independent maximization. Regardless of the rule, the outcome is efficient in the short run provided that $s^x + s^y = \bar{\pi}$.

This short run situation with an emissions permit system as a substitute for corrective taxation is analyzed. The number of firms in each industry is fixed, and firms may engage in costless bargaining. The presence of decentralized bargaining implies that the function of the emissions permit system is redundant.

Theorem 2: *Assume that there is an emissions permit system but no corrective taxation, as well as a fixed number of firms in each industry. Let* $(\gamma^*, p_x^*, p_y^*, x^*, y^*, b^*, \kappa_x^*, \kappa_y^*)$ *define an equilibrium with individuals maximizing utility taking prices as given and with firms maximizing joint profit taking prices as given. Then* $\gamma^* = 0$, $p_x^* = F'(x^*) + e_1(x^*, b^*)[n_y G_2(y^*, n_x e(x^*, b^*))]$, $p_y^* = G_1(y^*, n_x e(x^*, b^*))$, *and* $\kappa_x^* = \kappa_y^* = 0$ *yield* x^*, y^*, *and* b^* *at their first-best levels.*

With Coasian bargaining, the industries internalize the externality when choosing industry outputs to maximize joint profit. The bargaining gives firms the incentive to choose the socially efficient level of pollution. As a result, bargaining replaces the function of the emissions permit system completely. This redundancy does not upset the first-best allocation obtained through bargaining. With a zero equilibrium permit price, the regulator avoids revenue transfers that may induce behavior which upsets the socially efficient allocation.

The emissions permit system averts the complexity of the Buchanan-Stubblebine (1962) corrective taxation solution under the same conditions in the short run because the regulator does not confront the revenue transfer issue. The informational asymmetry between the regulator and the industries is crucial since the former cannot observe whether or not bargaining has occurred. If no bargaining occurs, then the emissions permit system is necessary to sustain the first-best allocation, and the regulator must transfer the permit revenue in a way that precludes any distortionary behavior. If bargaining occurs among firms, the emissions permit system is redundant, and no permit revenue exists.

4.2.2 Bargaining, Free Entry, and a Block Permit System

With costless bargaining and free entry, Hamilton *et al.* (1989) demonstrate that government intervention with the single instrument of a linear, Pigouvian tax fails to sustain an efficient allocation. They show that the use of a nonlinear tax system is one solution that sustains the first-best outcome under these conditions. This more complex Pigouvian system prevents excess entry into both the damaging and damaged industries by taxing away the ability to damage in the former and by preventing revenue from flowing to the latter.

In their scheme, the regulator chooses a tax rate on the output of the damaging industry above the optimum quantity. This rate prevents production above the first-best level of output. It also charges a lump-sum franchise tax for entry into the damaging industry that equals the uncharged tax on the portion of firms' total output that is less than the first-best level.[16] This franchise tax extracts the excess profit from the damaging industry and therefore removes the incentive for excess entry. Finally, the regulator's transfer of the franchise tax revenue to consumers implies that no revenue flows to the damaged industry. This condition guarantees the efficient number of firms in the damaged industry as well.

As a result, the nonlinear tax system eliminates any bargaining incentives that upset the socially optimal allocation. It avoids the problem of Buchanan and Stubblebine (1962) because the Pigouvian tax raises no net revenues. Firms observe no outflow of revenue and cannot benefit by bargaining to alter the level of the damaging activity. A socially inefficient number of firms in the damaging industry is not an issue because the lump-sum franchise tax extracts the residual revenue that damaging firms retain (in comparison to a linear Pigouvian tax).

With the possibility of entry into either industry, the key issue is whether or not an emissions permit system sustains the first-best allocation. Joint profit between the two industries is (as before) $\bar{\pi} = p_x n_x x + p_y n_y y - n_x F - n_y G - \gamma n_x e - \delta n_x b$. Bargaining yields the first order conditions in (*A1-A3*). Free entry implies that joint profit is zero; therefore, the additional constraint is

(9) $\bar{\pi} = p_x n_x x + p_y n_y y - n_x F - n_y G - \gamma n_x e - \delta n_x b = 0$.

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[16] The uncharged tax is set equal to marginal social damage evaluated at the first-best levels.

***Theorem 3:** With free entry and bargaining among firms, government regulation with only the single instrument of a conventional emissions permit system cannot sustain the first-best allocation.*

If firms engage in bargaining, then decentralized negotiation selects the first-best rate of abatement activity. Bargaining implies that the emissions permit system is unnecessary to yield the first-best choice of output in each industry. At the same time, bargaining induces inefficient entry into the polluting industry. At the efficient level of abatement, the equilibrium price of permits must be zero for the bargaining solution to sustain the efficient allocation. This price induces entry beyond the first-best number of firms into industry X because the acquisition of property rights is costless; therefore, positive profit exists in the industry.

One approach to solve this problem is the use of a block permit system. This system requires that potential entrants purchase a minimum quantity of permits equal to the first-best level of pollution per firm, $e^* = e(x^*, b^*)$. Firms must purchase these permits in blocks, not individually, at a price per block (Γ) equal to marginal social cost at the optimal level of pollution. One interpretation is that entry requires firms to purchase a license for an amount equal to marginal social cost. This license gives the firm the right to enter the industry and then emit e^* units of pollution.

***Theorem 4:** Assume firms in both industries take prices and the number of firms as given and that free entry into both industries occurs. If bargaining is possible among firms, then the following block permit system is sufficient to sustain the first-best allocation:* $\gamma^* = 0$, $\Gamma^* = [n_y^* G_2(y^*, n_x^* e(x^*, b^*))]e(x^*, b^*)$, $\kappa_x^* = \kappa_y^* = 0$, and $R^a = \Gamma^* n_x^*$.

The block permit system solves several problems. First, if bargaining is possible, a conventional permit system is problematic because the positive profit in the damaging industry induces inefficient entry. With a block permit system, the equilibrium permit price must still be zero to clear the market. The regulator must require that potential entrants purchase a minimum of one bundle of e^* permits at a price equal to marginal social cost at the optimum level of pollution. Essentially, the regulator charges this same amount for an entry license and includes a bundle of e^* permits with the license. The license allows entry into the industry and production that yields e^* emissions. This purchase requirement extracts the profit from the ability to damage. If the regulator does not set a minimum purchase requirement, then incumbent firms have an incentive to lower output slightly and sell permits to the entrant. The result is that industry output remains the same, but output per firm is less. Consequently, average production costs are too high because an inefficient number of firms comprises the industry.

Second, a block permit system eliminates the shut-down incentive present if the regulator uses a conventional permit system with only a franchise tax. A franchise tax equal to marginal social damage at the first-best level of pollution removes excess profit but is vulnerable to bargaining. In order to avoid franchise taxes, the industry may bargain to shut-down a subset of firms. The remaining firms increase average output per firm to keep revenue constant, and profit increases from the avoided franchise taxes. Permit blocking and charging a block price equal to the amount of a franchise tax implies that the industry cannot gain by bargaining to shut-down firms. The block purchase requirement of permits mimics the franchise tax on entry because it extracts all profit from the damaging activity from the industry. As a result, the block permit system is not susceptible to bargaining.

4.3 Conclusion

The possibility of decentralized bargaining among firms potentially upsets the efficient operation of an emissions permit system. With bargaining, firms from the damaging and damaged industries collude in their choice of outputs in order to maximize joint profit. This process implies that the damaging industry accounts for the effect of its pollution on the non-polluting industry's output. As a result, the bargaining process leads to the socially optimal level of pollution and therefore gives damaging firms the incentive to economize on their permit use. This behavior drives the market-clearing permit price to zero. With Pigouvian taxes, both types of firms can bargain in order to reduce tax payments. With a permit system, the firms instead bargain to reduce the amount paid for permits.

The implications of bargaining for the efficient operation of the permit market depend on whether free entry into the industries is possible. With a fixed number of firms, bargaining leads to the socially efficient level of output and replaces the permit market entirely. With free entry, however, the zero price of permits induces entry into the damaging industry. In this situation, the use of a conventional permit system leads to a socially inefficient number of firms in the damaging industry.

The alternative use of a block permit system solves this problem and sustains the socially efficient allocation. A block permit system requires firms to purchase permits in blocks only. Each block of permits contains a quantity of permits that enables the holder to emit exactly the efficient level of pollution per firm. A second requirement of this system is that a polluting firm must purchase a minimum of one block in order to enter the damaging industry. The final requirement is that the permit revenue is transferred to consumers as lump-sum income. This block permit system is analogous to a nonlinear tax scheme that sustains the social optimum under the same conditions.

Several important implications emerge from this analysis. The block permit system sustains the social optimum because it eliminates all gains from bargaining. With a conventional permit system, incumbent firms have an incentive to reduce their output and sell permits to entrant firms. The minimum purchase requirement for entry into the damaging industry eliminates the potential gains because it prevents each active firm in the damaging industry from reducing output by a small quantity. This minimum purchase requirement also serves to mimic the function of the franchise tax. Essentially, a franchise tax on entry into the damaging industry is inescapable in order to ensure the efficient number of firms.

4.4 Proofs

Proof of Theorem 1

Conditions (*2a-2e*) characterize the first-best allocation. Since $p_y = q_y$, (*4a*) and (*5b*) imply that (*2b*) is satisfied. Turning to (*2a*), conditions (*3a*) and (*5a*) imply that $\gamma = n_y G_2 > 0$ in order to sustain the first-best allocation. With the fixed supply, a permit price of $\gamma = n_y G_2$ clears the permit market, with industry Y demanding zero permits (from the complementary slackness condition in (*4b*)). Using $\gamma = n_y G_2$ and (*3b*), (*2c*) is satisfied. Conditions (*3a-3c*) with $\gamma = n_y G_2$ satisfy (*2d*) if $\kappa_x = 0$, and (*4a, 4c*) satisfy (*2e*) if $\kappa_y = 0$. The last requirement is that the government budget constraint is satisfied.

With $\kappa_x = \kappa_y = 0$, government budget balance occurs if consumers receive revenues from allowances as lump-sum payments.■

Proof of Theorem 2

Conditions (*2d*) and (*2e*) are irrelevant because the number of firms in each industry is fixed. Therefore, an outcome sustains the first-best allocation in the short run if and only if conditions (*2a-2c*) are satisfied. Firms bargain and choose x and y to maximize joint profit, $\bar{\pi}$ (see (*8*) for the program). The first order necessary conditions are

$$(A1)\quad \frac{\partial \bar{\pi}}{\partial x} = n_x\left[p_x - F' - e_1(n_y G_2 + \gamma)\right] = 0$$

$$(A2)\quad \frac{\partial \bar{\pi}}{\partial y} = n_y\left[p_y - G_1\right] = 0$$

$$(A3)\quad \frac{\partial \bar{\pi}}{\partial b} = n_x\left[-e_2(n_y G_2 + \gamma) - \delta\right] = 0 \quad .$$

Since $p_y = q_y$, (*5b*) and (*A2*) imply that (*2b*) is satisfied. The solution to the bargaining problem cannot sustain the first-best allocation unless $\gamma = 0$; if $\gamma > 0$, (*A3*) and (*2c*) are inconsistent. With respect to (*2a*), since $p_x = q_x$, (*5a*) and (*A1*) imply that $\gamma = 0$ satisfies (*2a*).■

Proof of Theorem 3

Substituting the first order conditions obtained under bargaining (*A1-A3*) into the zero profit condition (*9*) and rearranging terms yields

$$(A4)\quad \bar{\pi} = \left[xF' - F + n_y G_2(e_1 x + e_2 b) + \gamma(e_1 x - e + n_y G_2 b)\right]n_x + \left[G_1 y - G\right]n_y = 0 \quad .$$

In order for an emissions permit system with bargaining to potentially sustain the first-best outcome, then (*2c*) and (*A3*) must be consistent. They are consistent only if $\gamma = 0$. A zero permit price, along with (*5a*), ensures that bargaining sustains (*2a*). Conditions (*5b*) and (*A2*) satisfy (*2b*). Also, the first-best number of firms in industry *Y* requires that the last term in (*A4*) is zero. Imposing these conditions gives

$$(A5) \quad \overline{\pi} = xF' - F + n_y G_2 (e_1 x + e_2 b) = 0 \quad .$$

Since $n_y G_2 e \neq 0$, it is impossible to satisfy (*2d*) and (*A5*) simultaneously. ■

Proof of Theorem 4

The bargaining problem is

$$(A6) \qquad \max_{\{x,y,b\}} \quad \overline{\pi} \equiv p_x n_x x + p_y n_y y - n_x F(x) - n_y G(y, n_x e(x,b)) - \gamma n_x e(x,b) - \delta n_x b - n_x \kappa_x .$$

Using (*A1-A3*) and $\gamma = 0$, the bargaining solution now sustains the first-best allocation if $\Gamma = n_y G_2$ e. ■

CHAPTER 5
CONCLUDING REMARKS AND EXTENSIONS

The common theme linking these chapters is that strategic behavior by market participants upsets an emissions permit system's ability to attain environmental quality standards at minimum abatement cost. Essentially, the strategic incentives of polluting firms cause their profit-maximizing objectives to diverge from the cost-minimizing objectives of the system. In the first chapter, polluting firms possess market power in the permit market and may affect the market price strategically. In the second chapter, polluting firms are incumbent monopolies and may use banked permits as strategic instruments for entry deterrence purposes. In the final chapter, polluting firms strategically negotiate with firms in the damaged industry, and this bargaining affects the efficient function of the permit market if free entry is possible.

The implications of these chapters are likely to gain significance as the volume of trading activity becomes a more critical determinant of cost savings for participants. Phase II of the program, which begins in the year 2000, will impose a more stringent emissions constraint on firms because it decreases average emissions to 1.2 SO_2 lbs. /mmBtu. Consequently, the annual limit on emissions will decrease consistent with this tighter constraint. Some firms will be compelled to use additional permits as abatement activities become more costly at the margin. Phase II also expands the number of affected generating units. This expansion is especially important because many firms achieved Phase I compliance by switching production to unaffected units. As a result, unit switching may no longer be as viable an option. In addition, for some utilities, the tighter constraint on average emissions will imply that previously unaffected units will become affected units. With this more encompassing coverage, it is likely that larger differentials in marginal abatement costs will emerge among firms.

One lesson from the first chapter is that with or without strategic behavior in the permit market, its attainment of a specific level of emissions reduction at minimum cost may be problematic. With a competitive permit market, asymmetric regulatory treatment of emissions reductions options introduces a bias in a utility's choice between abatement and permits to achieve compliance. Given PUCs' current rate making position on abatement capital, only the full *inclusion* of permits in the rate base eliminates the distortion. Full or partial inclusion of permits in the rate base, however, opens a channel for strategic effects. The result is interaction between utilities' rate base incentives and strategic incentives.

The gradual transition to competitive markets in electricity generation does not make the potential for strategic behavior less acute, only its manifestations less complex. Even without any PUC rate base regulation, an unlikely scenario for some time, firms that can manipulate the permit price strategically certainly will behave strategically if they benefit from such behavior. The absence of rate base regulation simply eliminates an additional channel through which changes in the permit price affect a firm's profitability. In fact, the absence of this channel makes a lower volume of trading activity in the permit market even more likely because it eliminates the distortionary effects of weak buyers. If firms possess market power in the permit market, then their incentives are inconsistent with the attainment of emissions reduction at least cost.

The key theme of the second chapter is that polluting firms may utilize the emissions permit system to their strategic advantage. It provides an explanation for the observation that utilities are over-complying with respect to their reduction of emissions and banking their unused permits. Several nonstrategic explanations are possible for this behavior, but with the growth of clean independent power producers and the impending competitive restructuring of the electricity sector, the strategic explanation merits consideration.

An incumbent coal-fired utility banks permits in order to reduce its future environmental compliance costs and to prepare for the potential entry of a cleaner competitor into the market. The incumbent utility may either deter entry nonstrategically, deter entry strategically, or accommodate entry. In the strategic deterrence case, the incumbent firm banks exactly the critical quantity of permits necessary to deter entry.

The incumbent chooses a quantity of permits to bank for use in the second period that maximizes its two-period profit. Whether this choice accommodates or deters entry depends on the critical level of permits necessary for deterrence. This critical quantity is determined by the parameters that characterize the firms' demand and cost functions. One possible direction for future research is the use of a simulation to characterize the general conditions under which accommodation and deterrence occur.

The model demonstrates the three possible qualitative outcomes from banking permits; however, it does not incorporate a permit market into the analysis. The explicit introduction of a market complicates the model because collusion among incumbent firms is necessary to make banking a credible threat. This requirement implies that incumbent firms must monitor each other in the second period in order to ensure that no firm sells permits. An obvious extension for this chapter is an explicit attempt to model this collusion and to determine the conditions under which collusion makes banking credible.

The primary lesson from the third essay is that strategic bargaining among polluting and damaged firms may upset the effective operation of a conventional emissions permit system if free entry is possible. With bargaining, the damaging and damaged industries take into account the damage from the pollution in their determination of both industry outputs. This internalization of the externality induces firms in the damaging industry to economize on their use of permits. This behavior drives the equilibrium price of an emissions permit to zero and sustains the social optimum in the short run. In the long run, however, an inefficient number of firms enters the damaging industry because property rights to pollute are costless.

A block permit system addresses this problem because it eliminates the incentive for excess entry and any potential gains from bargaining. The minimum purchase requirement of a block of permits for entry into the damaging industry compels polluting firms to pay the social costs of their pollution. In this context, the purchase requirement serves as a franchise tax on entry into the damaging industry and ensures the socially efficient number of firms.

In general, the vulnerability of a conventional emissions permit system to decentralized bargaining weakens arguments promoting its use over Pigouvian taxes and other mechanisms for the control of negative externalities. The implementation of a block permit system solves this problem but like a conventional permit system, possesses the same problems with respect to implementation. Either permit system is equally, if not more difficult to implement, than a Pigouvian tax when the socially optimal level of pollution is *unknown*. With a Pigouvian tax, the regulator may need to set and reset the tax until it is equal to marginal social damage. With the permits, if the socially optimal level of pollution is unknown, then the regulator may issue the incorrect number of permits. Unlike the Pigouvian case, in which the regulator can reset the tax, the regulator cannot take back a permit.[1]

These chapters do not criticize the use of an emissions permit system to achieve a specific level of emissions reduction at least cost. Instead, they illustrate three different scenarios in which market imperfections prevent an emissions permit system from reducing pollution at minimum abatement cost. Strategic behavior by polluting firms in different contexts is the imperfection that makes emissions reduction a difficult objective. The results, implications, and directions for future research in these chapters raise important issues that deserve consideration in the evaluation of emissions permit market performances and in the design of future permit markets as well.

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[1] In the literature, claims that a permit system is easier to implement than a pollution tax implicitly assume that the socially optimal level of pollution is known. This information enables the regulator to issue the correct number of permits. In the case of a Pigouvian tax, the regulator requires information about firms' supply.

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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